Cochlear Implant Patient Assessment

Evaluation of Candidacy, Performance, and Outcomes

Second Edition



STUDENTS-HUB.com

Uploaded By: tuka abuzneid

René H. Gifford

Plural Publishing Inc.

A Volume in the Core Clinical Concepts in Audiology Series

Cochlear Implant Patient Assessment

Evaluation of Candidacy, Performance, and Outcomes

Second Edition

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Core Clinical Concepts in Audiology

Series Editor
Brad Stach, PhD

Basic Audiometry

Acoustic Immittance Measures by Lisa Hunter, Ph.D., FAAA and Navid Shahnaz, PhD., Aud(C)
Speech Audiometry by Gary D. Lawson, PhD and Mary E. Peterson, AuD
Basic Audiometry Learning Manual, Second Edition by Mark DeRuiter, MBA, PhD and Virginia Ramachandran, AuD, PhD
Pure-Tone Audiometry and Masking by Maureen Valente, PhD

Electrodiagnostic Audiology

Otoacoustic Emissions: Principles, Procedures, and Protocols, Second Edition by Sumitrajit Dhar, PhD and James W. Hall III, PhD
Objective Assessment of Hearing by James W. Hall III, PhD and De Wet Swanepoel, PhD

Cochlear Implants

Programming Cochlear Implants, Second Edition by Jace Wolfe, PhD and Erin C. Schafer, PhD
Cochlear Implant Patient Assessment: Evaluation of Candidacy, Performance, and Outcomes, Second Edition by René H. Gifford, PhD, CCC-A
Objective Measures in Cochlear Implants by Michelle Hughes, PhD, CCC-A

Balance and Vestibular Assessment

Electronystagmography/Videonystagmography (ENG/VNG), Second Edition by Devin L. McCaslin, PhD
Vestibular Lab Manual, Second Edition by Bre Lynn Myers, AuD
Rotational Vestibular Assessment by Christopher K. Zalewski, PhD

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Pediatric Audiology

Pediatric Amplification: Enhancing Auditory Access by Ryan W. McCreery, PhD, CCC-A and Elizabeth A. Walker, PhD, CCC-A/SLP

Cochlear Implant Patient Assessment

Evaluation of Candidacy, Performance, and Outcomes

Second Edition

René H. Gifford, PhD, CCC-A

STUDENTS-HUB.com

Uploaded By: tuka abuzneid

Plural Publishing Inc.

PLURAL PUBLISHING
INC.

5521 Ruffin Road
San Diego, CA 92123

e-mail: information@pluralpublishing.com
Web site: https://www.pluralpublishing.com

Copyright © 2020 by Plural Publishing, Inc.

Typeset in 11/13 Palatino by Achorn International
Printed in the United States of America by Integrated Books International

All rights, including that of translation, reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, recording, or otherwise, including photocopying, recording, taping, Web distribution, or information storage and retrieval systems without the prior written consent of the publisher.

For permission to use material from this text, contact us by
Telephone: (866) 758-7251
Fax: (888) 758-7255
e-mail: permissions@pluralpublishing.com

Every attempt has been made to contact the copyright holders for material originally printed in another source. If any have been inadvertently overlooked, the publishers will gladly make the necessary arrangements at the first opportunity.

Library of Congress Cataloging-in-Publication Data

Names: Gifford, René H., author.
Title: Cochlear implant patient assessment : evaluation of candidacy, performance, and outcomes / René H. Gifford.
Other titles: Core clinical concepts in audiology.
Description: Second edition. | San Diego, CA : Plural, [2020] | Series: Core clinical concepts in audiology | Includes bibliographical references and index.
Identifiers: LCCN 2019024005 | ISBN 9781635501285 (paperback) | ISBN 1635501288 (paperback) | ISBN 9781635501384 (ebook)
Subjects: MESH: Cochlear Implants | Cochlear Implantation | Hearing Loss—rehabilitation | Outcome and Process Assessment (Health Care) | Patient Selection | Persons With Hearing Impairments—rehabilitation
Classification: LCC RF305 | NLM WV 274 | DDC 617.8/822—dc23
LC record available at https://lccn.loc.gov/2019024005

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table of Contents

Preface *vii*
Acknowledgments *ix*
Contributors *xi*

1 **FDA Candidacy for Cochlear Implantation** **1**
René H. Gifford, Cedric Navarro, Patricia B. Macy, and Laura Blair

2 **Adult Cochlear Implant Candidate Selection** **13**
René H. Gifford

3 **Pediatric Cochlear Implant Candidate Selection** **37**
René H. Gifford

4 **Role of the Speech–Language Pathologist in the Assessment of Pediatric Cochlear Implant Candidacy** **61**
Emily Lund

5 **Cochlear Implant Surgery: Clinical Implications of Variable Anatomy** **77**
Robert F. Labadie

6 **Nontraditional Candidates for Cochlear Implantation** **91**
René H. Gifford

7 **Elements of Postoperative Assessment in Adult Implant Recipients** **111**
René H. Gifford

8 **Elements of Postoperative Assessment: Pediatric Implant Recipients** **125**
René H. Gifford

STUDENTS-HUB.com Uploaded By: tuka abuzneid

9 **Role of the Speech–Language Pathologist and Teacher of the Deaf in the Postoperative Assessment of Children** **145**
Emily Lund

10 **Assessing Pre- and Postoperative Outcomes for Adults and Children: What Does the Future Hold and What Might We Be Missing?** **159**
René H. Gifford

Index *179*

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Preface

Coursework included in the education of student clinicians and educators in the fields of audiology, speech-language pathology, and deaf education tends to focus considerable attention on the history and evolution of cochlear implants, including iterations in implant design, signal processing, and recipient outcomes. This information is infinitely valuable and necessary to understand cochlear implants and to ultimately apply that knowledge to the patient and student. What tends to be overlooked in academic instruction, however, is the applied knowledge base required for cochlear implant patient assessment in everyday clinical practice—something that cannot generally be imparted solely from clinical and educational practicum. Clinicians from around the world have phoned and e-mailed with questions regarding candidate selection, preoperative evaluation protocol, counseling, and postoperative assessment. Questions range from recommending implantation for patients who may not fit the traditional implant candidate profile to sound-field calibration for pre- and postimplant testing to recommendations for additional assessments that may yield diagnostic information not currently provided by the standard battery. Given that the numbers of adult and pediatric implant recipients continue to increase, more clinicians will be expected to gain and maintain a level of experience surrounding the clinical management of this special population. This book can serve as a guidebook, delivering clinically relevant information to audiologists, speech-language pathologists, and deaf educators regarding the assessment tools and therapeutic intervention that are critical during the pre- and postimplant periods.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Acknowledgments

There are a number of individuals to whom I must express my sincerest gratitude for their contributions and assistance in completing this book. First, I would like to individually thank my contributors. Emily Lund, PhD, CCC-SLP, graciously offered her writing and clinical expertise in childhood hearing loss and speech-language pathology for Chapters 4 and 9. Dr. Lund is a rigorous and thoughtful researcher as well as a highly skilled speech-language pathologist. Most of her work has focused on development of language, literacy, and preliteracy skills in children with developmental disabilities, with a particular focus on children with cochlear implants. Dr. Lund is a trusted colleague and I greatly value her opinion and knowledge.

Robert F. Labadie, MD, PhD, MMHC, FACS, offered his valuable clinical and scientific experiences as an otologic surgeon to write Chapter 5. Not only is Dr. Labadie an exceptional surgeon and one of the most critically thinking clinician-scientists that I have ever met, but his lectures on cochlear implant surgery and ear anatomy are the highlight of my cochlear implant class each year! This chapter is a great addition to the second edition.

My Chapter 1 coauthors—Laura Blair, AuD, Patricia B. Macy, MA, and Cedric Navarro—are all so impressive in their expertise regarding implant regulation. They have taught me so much more than I could ever imagine about a dry, yet critically important topic. In fact, I've even come to enjoy reading about regulatory matters. I must also thank AuD students, David Kessler and Andie DeFreese, for providing their valuable assistance with organizing the references for this book.

Special thanks must be extended to my coworkers and colleagues, some of whom volunteered their time to read and provide comments on earlier versions of this work, and all of whom are instrumental in developing, revising, and implementing our clinical assessment protocols. They are dedicated to best practices and their patients reap the benefits! Specifically I want to thank Linsey Sunderhaus, AuD, Susan Amberg, AuD, Jourdan Holder, AuD, Bob Dwyer, AuD, Kelley Corcoran, AuD, Sara Unrein, AuD, Christine Brown, AuD, Adrian Taylor, AuD, Stephanie Yaras, AuD, Kelsey Hatton, AuD, and Ally Sisler-Dinwiddie, AuD. You are all amazingly talented clinicians and I learn so much from each of you every day.

Finally, and most importantly, I want to thank my family, to whom I am completely committed (despite the fact that my laptop and I appear inseparable). My sons, Levi, Jacob, and Aidan, are a patient group. My boys have always been supportive and continue to be both excited and surprised that Mom could write a book—even if it is a "boring textbook." My husband, Branden, is the best husband this crazy, unorganized, and absent-minded woman could have ever imagined. I am certain that he was handpicked for me and I hope that he accepts my thanks for his love and support and all my apologies for working around the clock.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Contributors

Laura Blair, AuD
Director, Regulatory Affairs
Cochlear North America
Centennial, Colorado
Chapter 1

René H. Gifford, PhD, CCC-A
Professor
Hearing and Speech Sciences
Vanderbilt University Medical Center
Director
Cochlear Implant Program
Vanderbilt Bill Wilkerson Center
Nashville, Tennessee
Chapters 1, 2, 3, 6, 7, 8, and 10

Robert F. Labadie, MD, PhD, MMHC, FACS
Robert H. Osoff DMD, MD, Endowed Directorship for Translation Research in Otolaryngology
Vice Chair, Chief Research Officer
Professor of Otolaryngology—Head and Neck Surgery
Professor of Biomedical Engineering
Vanderbilt University
Nashville, Tennessee
Chapter 5

Emily Lund, PhD, CCC-SLP
Associate Professor
Department of Communication Sciences and Disorders
Texas Christian University
Fort Worth, Texas
Chapters 4 and 9

Patricia B. Macy, MA
Vice President
Risk Management
MED-EL Corporation
Durham, North Carolina
Chapter 1

Cedric Navarro
Vice-President
Global Regulatory and Clinical Affairs
Advanced Bionics
Valencia, California
Chapter 1

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

I believe in cochlear implants like I believe that the sun will rise and set each day. In fact, it's not really a belief for me; it's a universal and undisputable truth. One cannot witness the life-altering outcomes for the recipients and their families and not believe wholeheartedly in the power of this technology. My passion for cochlear implants is rivaled only by my enthusiasm for audiology and hearing science. I know of no other field employing a more dedicated and impassioned group of interdisciplinary professionals working toward the common goal of improving hearing outcomes and quality of life for all individuals with hearing loss. It is nothing short of a blessing to be granted the opportunity to work with cochlear implant recipients and their families. Every single patient has impacted me in his or her own special way and I can only hope that I have helped each patient even if only in some small way. Every patient with whom I have worked has educated, humbled, challenged, and inspired me daily, and it is these special individuals who have motivated me to begin, and more importantly to finish, this book. If this work furthers the education of a single student, clinician, teacher, patient, or parent, then I will consider my efforts meaningful. Thus, this work is dedicated to all cochlear implant recipients—young and old—and the professionals who devote their time and talents to ensure that every cochlear implant recipient achieves his or her own highest potential.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

1

FDA Candidacy for Cochlear Implantation

René H. Gifford, Cedric Navarro, Patricia B. Macy, and Laura Blair

INTRODUCTION

The process of obtaining United States Food and Drug Administration (FDA) approval for biomedical devices is largely a foreign process to the working clinician; however, this process affects every clinician working with individuals who have hearing aids, bone-anchored implants, and/or cochlear implants. There are a number of misconceptions about FDA-labeled indications for adults and children and how these labeled indications affect the clinician's role in determining implant candidacy. Chapter 1 describes aspects concerning FDA approval for biomedical devices, including the nature of the approval process, manufacturer-initiated clinical trials required for approval, as well as the role of the FDA in the regulation of biomedical devices. The chapter concludes with descriptions of the current FDA-labeled criteria for both adult and pediatric populations.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

COCHLEAR IMPLANTS: FDA-REGULATED BIOMEDICAL DEVICES

The FDA is responsible for protecting public health by ensuring that certain products are safe and effective, as well as monitoring such products for continued safety. The mission of the FDA is specifically listed as having the "responsibility of protecting the public health by assuring the safety, efficacy and security of human and veterinary drugs, biologic products, medical devices, our nation's food supply, cosmetics, and products that emit radiation" (FDA, 2018b). To carry out this mission, the FDA is organized into a number of centers and offices, each of which is focused on specific technologies. The center that is responsible for overseeing medical devices, such as cochlear implants, bone-anchored implants, and hearing aids, is the Center of Devices and Radiological Health (CDRH). The CDRH center regulates

all industry that manufactures, repackages, relabels, or imports medical devices in the United States. The CDRH comprises several offices, each of which play a role in the regulation of medical devices. Those offices and their areas of responsibility and roles within the CDRH are shown in Table 1–1.

The U.S. Congress enacted the Medical Device Amendments of 1976 in order to "provide for the safety and effectiveness of medical devices intended for human use." The Medical Device Amendments were added to the Federal Food, Drug, and Cosmetic Act (FD&C Act), which was originally passed in 1938. The Medical Device Amendments established three regulatory classes for medical devices based on the degree of control necessary to ensure safety and effectiveness: classes I, II, and III.

Class I devices are considered low risk to the user. Class I devices constitute 47% of all regulated devices in the U.S. and with the passing of the 21st Century Cures Act (Rep Upton, 2016), 95% of Class I devices are now considered exempt from FDA review. Examples of exempt Class I devices include elastic bandages, patient scales, canes, otoscopes, and hearing aids. Nonexempt Class I devices require that the device manufacturer provide the FDA with premarket notification (510(k)) and listing prohibitions against adulteration and misbranding, and rules for good manufacturing practices. 510(k) premarket notification requires that a manufacturer prove *substantial equivalence* to an existing legally marketed device, which would render it exempt from premarket approval (PMA). Examples of *nonexempt* Class I devices are dental chairs and accessories, wheelchairs, and blood bank supplies.

Class II devices are considered slightly higher risk to the user and constitute 43% of medical devices. Class II devices have the same requirements as nonexempt Class I devices, but additionally require that the manufacturer provide the FDA with performance standards. As with Class I devices, some Class II devices are considered exempt from premarket notification 510(k), including wireless hearing aids, audiometers, and tympanometers, Examples of nonexempt Class II devices

Table 1–1. Responsibilities of the Offices of the Center of Devices and Radiological Health

Office Name	*Area of Responsibility*
Office of Product Evaluation and Quality (OPEQ)	New organization focused on the Total Product Lifecycle of medical devices. This new Super Office combines the prior Office of Device Evaluation, Office of Compliance, and Office of Surveillance and Biometrics ■ Review and approval of Class III devices including design, manufacturing, and quality control changes ■ Review and approval of investigational device exemptions required to collect clinical data in support of a device application ■ Enforces regulatory compliance of industry ■ Monitor safety and efficacy of medicals device through the product lifecycle
Office of Policy (OP)	Provides oversight and leadership in the development of regulations, guidances, policies, and procedures concerning medical device and radiation-emitting products
Office of Science and Engineering Laboratories (OSEL)	Scientific review of Class III device applications when requested by either ODE or OC
Office of Strategic Partnerships and Technology Innovation	Provides leadership for all scientific collaborative and emerging technologies

STUDENTS-HUB.com Uploaded By: Luka abuzneid

are x-ray systems, bone-anchored implants, and otoacoustic emission equipment.

Class III medical devices are those that are implanted, considered to sustain or support life, and present a potentially unreasonable risk of illness or injury to the recipient (FDA, 2019). Class III devices constitute just 10% of all medical devices in the U.S. Class III devices have all the same requirements as nonexempt Class I and II devices, but additionally require PMA. PMA is a required process of FDA scientific review to ensure safety and effectiveness prior to marketing a device that does not qualify for review based on substantial equivalence. Examples of Class III devices are implantable pacemakers, implanted neuromuscular stimulators, and cochlear implants; thus, cochlear implants are placed in the most highly regulated category of medical devices.

In order to obtain PMA for a new device without substantial equivalence, cochlear implant manufacturers must submit an application to the CDRH for review and consideration (see Table 1–1). The FDA has specific branches within the Office of Product Evaluation and Quality (OPEQ) (Table 1–1), each having the knowledge and professional expertise to review the specific applications. Cochlear implants, middle ear implants, bone-anchored implants, and hearing aids are the responsibility of the Office of Ophthalmic, Anesthesia, Respiratory, ENT, and Dental Devices. The reviewers in this branch are audiologists, hearing scientists, engineers, and ENT physicians/surgeons. OPEQ review panels can be composed of both FDA employees, as well external consultants.

FDA REVIEW PROCESS FOR COCHLEAR IMPLANTS

STUDENTS-HUB.com Uploaded By: tuka abuzneid

New Devices

For new cochlear implant internal devices, processors, or significant design changes to internal and/ or external devices for which a *substantially equivalent* device does not exist, the implant manufacturers must submit a PMA application to the FDA, which is reviewed by the Office of Ophthalmic, Anesthesia, Respiratory, ENT, and Dental Devices for consideration. If the ODE reviewers decide that a more detailed scientific review is required in order to determine the safety and efficacy of the product in question, a request will be made for further review by staff from the Office of Science and Engineering Laboratories (OSEL). The OSEL has a staff of scientific reviewers who support all types of medical devices and associated technologies. For cochlear implants, there are OSEL reviewers with specialties in material sciences, mechanical engineering, neurophysiology, and hermeticity.

Existing Devices

If a cochlear implant manufacturer institutes changes to manufacturing and/or quality control for existing devices that affect safety or efficacy, the Office of Ophthalmic, Anesthesia, Respiratory, ENT, and Dental Devices must be notified prior to the initiation of those changes. They review the proposal and can also request a detailed scientific review by OSEL staff. As part of a recent FDA reorganization, the OPEQ was created to focus on the Total Product Lifecycle approach. The prior Offices of Compliance and Surveillance and Biometrics were combined with the Office of Device Evaluation. This approach leverages the expertise and experience of the technical review team to ensure the continued safety and effectiveness of medical devices after approval. OPEQ is responsible for determining whether a manufacturer is in compliance with applicable legal requirements for manufacturing the devices, monitors device recalls, and performs regular facility inspections. OPEQ is also responsible for the evaluation and trending of medical device reports (MDRs). MDRs can be filed by manufacturers, patients, and/or health care providers for medical device failures or adverse events that result in harm.

FDA FUNDING

The FDA application, review, and monitoring of medical devices is intensive both in terms of

Table 1–2. The 2019 Medical Device User Fees Most Applicable for Cochlear Implant Manufacturers

Application Type	*Standard Fee (U.S. $)*	*Small Business Fee (U.S. $)*
Premarket approval (PMA)	$322,147	$80,537
Panel-track supplement	$241,610	$60,403
180-day supplement	$48,322	$12,081
Real-time supplement	$22,550	$5,638
510(k)	$10,953	$2,738
30-day notice	$5,154	$2,577
Annual fee for periodic reporting on a class III device	$11,275	$2,819

the required time and personnel. Although these processes were put in place to ensure the safety and efficacy of medical devices for the American consumer, limited governmental funding is provided in order to carry out its mission and all associated responsibilities. In fiscal year 2019, the U.S. Congress allocated $5.8 billion ($3.2 billion in budget authority) for the FDA's annual budget (FDA, 2018a). According to U.S. census bureau data, the national population in 2019 was 328,247,710 (Worldometers, 2019); thus, the 2019 FDA budget taken from tax dollars (i.e., budget authority) amounted to just $9.75 allocated for each individual living in the U.S. to carry out all responsibilities related to its mission. An obvious question centers on the feasibility of the FDA completing all of its assigned tasks and responsibilities in order to protect and promote public safety on such as limited budget. A second follow-up question centers on the source of the remaining $2.6 billion in the 2019 fiscal year budget. The answer to this question lies in the Medical Device User Fee and Modernization Act.

In 2002, the Medical Device User Fee and Modernization Act (MDUFMA), PL 107-250, was passed to amend the FD&C Act. The most significant provision of the MDUFMA—and that which is most relevant for cochlear implant manufacturers—was that which allowed the FDA to collect user fees for certain premarket reviews. Those PMAs subject to a user fee in accordance with MDUFMA include original PMAs, premarket reports, product development protocols, panel-track supplements, 180-day supplements, and real-time supplements. The user fees are updated annually and are available to the public on the FDA's website. Table 1–2 lists the 2019 medical device user fees most applicable for cochlear implant manufacturers.

DEVICE MODIFICATIONS REQUIRING FDA PMA APPROVAL

It is not the case that user fees are required only when first bringing a cochlear implant to market. Rather, PMA supplements are required in many cases when existing products are modified. One could argue that such tight regulation has the potential to inhibit product growth and development in the field of cochlear implants; however, the FDA explicitly states that the *least burdensome approach* should be taken in all areas of medical device regulation. It is this "least burdensome approach" to regulation that has prompted the development of multiple avenues for supplemental PMA.

A panel-track PMA is a supplement to an already approved PMA for which the manufacturer is requesting a "significant change in design or performance of the device, or a new indication

STUDENTS-HUB.com Uploaded By: tuka abuzneid

for use of the device, and for which clinical data will be necessary to provide a reasonable assurance of safety and effectiveness" (FDA, 2018d). For example, any time that the implant manufacturers revise indications or criteria for implantation, they are required to complete a clinical trial, which itself requires FDA approval via investigational device exemption (IDE). Once the IDE is approved, the study is carried out at a number of approved medical centers across the country. Following completion of the study, the manufacturer would then submit an application to the FDA for approval of the revised indications via a panel-track PMA supplement. This process is time and personnel intensive, as well as costly to the manufacturer. It is for these reasons that the manufacturers do not regularly revise labeled indications for implantation despite the widespread knowledge that individuals with less severe hearing losses and better speech recognition scores, as well as children under 12 months of age, benefit from cochlear implants (Chapter 6). Manufacturers are required to submit a 180-day PMA supplement if they intend to make significant changes that affect the safety and effectiveness of the device. Manufacturer-requested changes to components, materials, design, specification, software, color additives, or labeling are considered appropriate for 180-day supplements. In some cases, the FDA may determine that the requested changes are sufficiently complex, requiring a full PMA review by an outside advisory panel. In other cases, the FDA may determine that the proposed changes are minor and thus, a *real-time supplement* may apply. A real-time supplement is one during which the supplement application is reviewed during a meeting or conference call and requires the review of only one scientific discipline.

Cochlear implant manufacturers are required to submit a 30-day notice when they plan to make changes to the manufacturing procedure or changes in the manufacturing method that could affect the safety and effectiveness of their device. A 30-day notice is sufficient as long as the changes do not alter performance, or design specifications, or the designated physical or chemical specifications of a device. Changes to the manufacturing procedure or method of manufacturing that do not affect the safety or effectiveness of the device must be submitted in the periodic report submitted to the FDA that is usually referred to as an annual report.

If a 30-day notice contains device-design or labeling changes in addition to manufacturing changes, the submission will automatically be converted to a 180-day PMA. If the change qualifies for a 30-day notice and complete information has been submitted, the device may be distributed 30 days after the date on which the FDA received the notice. If the information submitted is not adequate, within 30 days of receipt the FDA will provide notice that a 135-day PMA supplement is needed and will describe the additional information or action required for acceptance of the change. If no action occurs within 30 days of the FDA's receipt of the 30-day notice and payment of the user fee, the device may be distributed without further action from the FDA.

LABELED INDICATIONS FOR COCHLEAR IMPLANTATION AND OFF-LABEL USAGE

Current cochlear implant labeled indications (i.e., candidacy criteria) are listed in the physician's package insert that can be found in the packaging of each internal device. Contrary to popular belief, the FDA is not responsible for designating the criteria (indications) for cochlear implantation. Rather, the manufacturers submit an application for PMA outlining the indications for their device. Thus, it is the role of the FDA to either approve or reject the submitted application for PMA and the manufacturer-defined indications. If ultimately approved, the manufacturer-defined indications for implantation are then listed as the FDA criteria for use of that device. These criteria are often referred to as the FDA labeled indications or FDA candidacy criteria; however, the indications are *approved* by the FDA, but not set by the FDA.

What is important for the clinician to recognize in this process is that the FDA governs industry, not the individual clinician nor implant center. The industry—or in this case, the cochlear implant manufacturer—is strictly prohibited from promoting any off-label usage of its device. As is

STUDENTS-HUB.com Uploaded By: tuka abuzneid

discussed in Chapter 6, despite considerable evidence in support of expanded cochlear implant candidacy criteria, the implant manufacturers are simply not permitted to recommend implantation for individuals not meeting labeled indications. Clinicians, however, are granted the professional judgment to make clinical determinations for their patients about the suitability of cochlear implant candidacy. In fact, the FDA has provided an information sheet entitled "Off-Label and Investigational Use Of Marketed Drugs, Biologics, and Medical Devices" (FDA, 2018c), which details the conditional approval of off-label usage of medical devices, drugs, and biologics as recommended by licensed clinicians. This information sheet explicitly endorses off-label usage of a marketed medical device when the intent is for clinical practice and not for research purposes. In this document, the FDA counsels that if clinicians recommend off-label usage of a medical device, they have the responsibility to ensure that the following three conditions are met:

1. Be well informed about the product.
2. Base its use on firm scientific rationale and on sound medical evidence.
3. Maintain records of the product's use and effects.

Off-label usage is nothing new in pharmaceuticals, biologics, and medical devices. For pharmaceuticals, estimates are that 20% to 60% are routinely prescribed for off-label usage across all medical specialties (Frattarelli et al., 2014; Jansen, 2011; Smieliauskas, Sharma, Hurley, de Souza, & Shih, 2018; Valeo, 2011; Van Allen, Miyake, Gunn, Behler, & Kohlwes, 2011). In fact, the U.S. Supreme court ruled that off-label use of medical devices is an "accepted and necessary corollary of the FDA's mission" and that clinicians can "prescribe or administer any legally marketed device to a patient without limitation or interference" (Buckman, 2001).

Clinicians may discuss off-label use with individual patients and with colleagues in clinic and at scientific conferences; however, they are not allowed to advertise or market off-label usage to the general public. Such advertising would constitute a violation of the FD&C Act, which states that "a licensed practitioner may not promote a medical device for use(s) for which they have not received FDA clearance." For example, if a cochlear implant center took out an ad stating that individuals with mild to moderate hearing loss might benefit from cochlear implants and should thus consider coming into the center for evaluation, this would be direct violation of FDA policy. Off-label usage of medical devices has become such common practice that even the Tennessee appellate court has ruled that this could be considered "standard of care" (Richardson, 2000). Despite the ubiquity of off-label device usage across all fields, what remains critical is that we as clinicians respect the FDA's position on the stance of off-label cochlear implantation (FDA, 2018c) and consider the needs of each individual patient with our colleagues and members of the interdisciplinary cochlear implant team.

CURRENT COCHLEAR IMPLANT CRITERIA FOR ADULTS AND CHILDREN

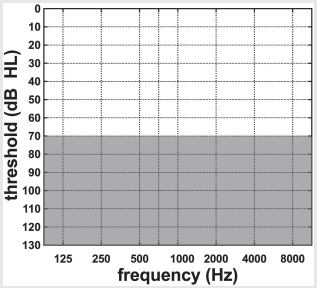
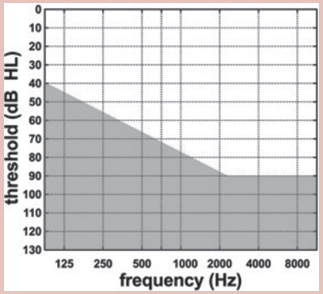
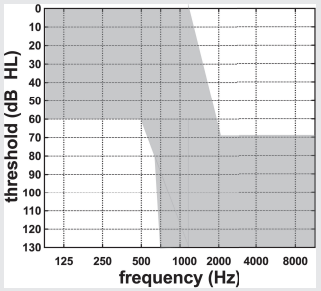
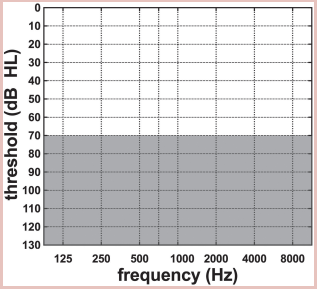
Cochlear implant criteria, also referred to as labeled indications for cochlear implantation, have been set independently and differently by each of the cochlear implant manufacturers. Also note that Cochlear and MED-EL have a secondary set of indications for the electric and acoustic stimulation (EAS) systems and MED-EL has a new indication specifically for individuals with single-sided deafness (SSD; see Chapter 6). The current adult and pediatric implant criteria are shown in Tables 1–3 and 1–4, respectively.

Note that there is considerable variability across the manufacturers for both adult and pediatric candidacy. In Table 1–3, for adult indications, Cochlear makes reference to differing speech recognition criteria for the ear to be implanted versus the "best-aided condition." On the other hand, AB, MED-EL, and CMS reference speech recognition performance in the best-aided condition. (Chapter 2 discusses more recent recommendations regarding individual ear testing and focusing on the ear to be implanted.) For all but the EAS systems, aided speech recognition references sentence stimuli for determining candidacy.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com

Table 1–3. Labeled Indications for Adult Cochlear Implantation as Shown for Advanced Bionics, Cochlear Americas, MED-EL, and CMS.

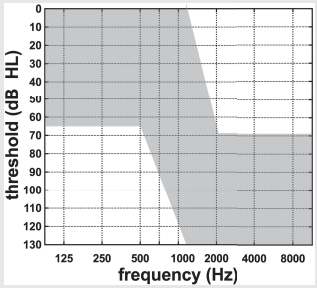
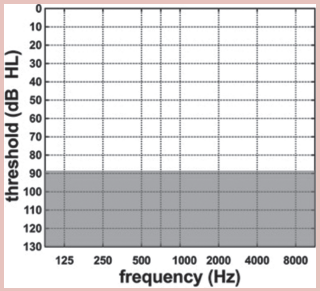
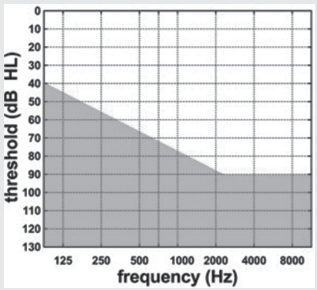
Adult indications	*Audiometric Thresholds*		*Speech Recognition Performance*
Advanced Bionics HR90K Ultra 3D		severe-to-profound, bilateral sensorineural hearing loss (>70 dB HL)	≤50% for open-set sentence recognition (HINT Sentences)
Cochlear Profile & Profile Plus		moderate to profound hearing loss in the low frequencies and profound (≥90 dB HL) hearing loss in the mid-to-high frequencies	≤50% correct in the ear to be implanted (≤60% in the best-aided condition) on recorded tests of open set sentence recognition
Cochlear Hybrid-L24		thresholds ≤60 dB HL through 500 Hz and ≥70 dB HL for 2000+ Hz	≤60% CNC word recognition in ear to be implanted, ≤80% CNC in contralateral ear
MED-EL Synchrony & Synchrony 2		bilateral severe to profound sensorineural hearing loss (pure-tone average ≥70 dB HL)	≤40% in best-aided listening condition on recorded tests of open-set sentence recognition (HINT sentences)

continues

Uploaded By: tuka abuzneid

STUDENTS-HUB.com

Table 1–3. *continued*

Adult indications	*Audiometric Thresholds*		*Speech Recognition Performance*
MED-EL Synchrony & Synchrony 2 EAS		thresholds ≤65 dB HL through 500 Hz and ≥70 dB HL for 2000+ Hz	≤60% CNC word recognition in the ear to be implanted and in the contralateral ear
MED-EL Synchrony & Synchrony 2 for single-sided deafness (SSD) and asymmetric hearing loss (AHL)		thresholds ≥90 dB HL in ear to be implanted	≤5% CNC word recognition in ear to be implanted
Centers for Medicare/ Medicaid Services (CMS)		bilateral moderate to profound sensorineural hearing loss at 500 Hz, 1000 Hz, and 2000 Hz	≤40% in best-aided listening condition on recorded tests of open-set sentence recognition

Uploaded By: tuka abuzneid

STUDENTS-HUB.com

Table 1–4. Labeled Indications for Cochlear Implantation for Pediatric Implant Recipients as Shown for Advanced Bionics, Cochlear, and MED-EL

		Auditory Skills and Speech Recognition		
Pediatric indications	***Audiometric Thresholds***	***Younger Children***	***Older Children***	***Amplification requirements***
Advanced Bionics HR90K Ultra HR90K Ultra 3D	Severe-to-profound bilateral sensorineural hearing loss (>70 dB HL)	<4 years of age: failure to reach developmentally appropriate auditory milestones (such as spontaneous response to name in quiet or to environmental sounds) measured using the Infant-Toddler Meaningful Auditory Integration Scale or Meaningful Auditory Integration Scale or <20% correct on a simple open-set word recognition test (Multisyllabic Lexical Neighborhood Test) administered using monitored live voice (70 dB SPL)	4 years of age: <12% on a difficult open-set word recognition test (Phonetically Balanced-Kindergarten Test) or <30% on an open-set sentence test (Hearing In Noise Test for Children) administered using recorded materials in the sound field (70 dB SPL)	Use of appropriately fitted hearing aids for at least 6 months in children 2 through 17 years of age, or at least 3 months in children 12 through 23 months of age. The minimum duration of hearing aid use is waived in the presence of ossification concerns.
Cochlear Profile and Profile Plus	12 to 23 months: Bilateral profound sensorineural hearing loss 24 months up to 18 years: Bilateral severe-to-profound sensorineural hearing loss	Lack of progress in the development of simple auditory skills as quantified on a measure such as the Meaning Auditory Integration Scale or the Early Speech Perception test	≥30% correct on Multisyllabic Lexical Neighborhood Test (MLNT) or Lexical Neighborhood Test (LNT), depending upon the child's cognitive and linguistic skills	Use of appropriate amplification and participation in intensive aural habilitation over a three- to six-month period
Med El SYNCHRONY SYNCHRONY 2	Profound, bilateral sensorineural hearing loss with thresholds of 90 dB HL or greater at 1000 Hz	Lack of progress in the development of simple auditory skills in conjunction with appropriate amplification	<20% correct on the Multisyllabic Lexical Neighborhood Test (MLNT) or Lexical Neighborhood Test (LNT), depending upon cognitive ability and linguistic skills	Use of appropriate amplification and participation in intensive aural habilitation over a three to six month period—radiological evidence of cochlear ossification may justify a shorter trial with amplification

Uploaded by Tuka abuzneid

For Cochlear and MED-EL EAS systems, however, monosyllabic word recognition is listed. In fact, there is a trend for the implant manufacturers to be moving toward adoption of a monosyllabic-based criterion for determining adult candidacy in the U.S. (Sladen et al., 2017). Use of a monosyllabic word criterion would allow us to better assess peripheral auditory processing, as monosyllables do not allow a listener to "fill in the gaps" that she or he may have missed due to hearing loss. Sentences, on the other hand, have rich lexical context allowing a listener to use both peripheral processing or "bottom-up processing," as well as "top-down processing." Monosyllabic word tests will not allow the listener the same use of top-down repair strategies as sentence tests and thus provide a more accurate representation of the listener's auditory resolution.

In Table 1–4, for pediatric criteria, none of the manufacturers reference criteria based on the ear to be implanted. In fact, the labeled indications for pediatric candidacy are much more stringent than those listed for adult candidacy. (Chapter 3 discusses pediatric candidate selection in depth, and Chapter 6 covers those cases for which expanded criteria are warranted.)

Unlike speech recognition criteria, the contraindications for cochlear implantation are consistent across both manufacturer and recipient age. The contraindications for cochlear implantation are as follows:

- Hearing loss originating in the auditory nerve or central auditory pathway
- Active external or middle ear infections
- Cochlear ossification preventing electrode insertion
- Cochlear nerve deficiency
- Tympanic membrane perforations associated with recurrent middle ear infections
- Allergy and/or intolerance of device materials (i.e., medical grade silicone, platinum, and titanium)

In addition to the contraindications listed above, CMS lists an additional contraindication as lacking the cognitive ability to use auditory clues and/or unwillingness to undergo an extended program of rehabilitation.

CONCLUSION

Indications for cochlear implantation are different for all three cochlear implant manufacturers, and different yet for individuals covered by Medicare. Considering pediatric candidates, indications vary both with the child's age and developmental state; thus, it is no wonder that determining implant candidacy is not a straightforward process for either adult or pediatric candidates.

It is expected that indications will broaden over time; however, as discussed in this chapter, the process by which industry modifies labeling is time intensive and expensive. The FDA has specified the provisions allowing for off-label usage of medical devices as determined medically necessary by licensed medical professionals. Of course, insurance restrictions exist for patients with government insurance and even some private, commercial insurance plans. Thus, if we are to offer this technology to the individuals who can derive significant communicative benefit, the implant industry will ultimately need to conduct FDA-approved clinical trials via IDE and a subsequent PMA supplement to change labeled indications. As stated in the Introduction, although the process of FDA approval for biomedical devices tends to be a foreign process for the working clinician, it undoubtedly affects our role in determining implant candidacy.

REFERENCES

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Buckman. (2001). Buckman Company v. Plaintiffs' Legal Committee. 531 U.S. 341

FDA. (2018a). Food and Drug Administration (FDA): Justification of Estimates for Appropriations Committees. Washington, DC.

FDA. (2018b). No title. Retrieved from What We Do website: https://www.fda.gov/AboutFDA/WhatWeDo/#mission

FDA. (2018c). Off-Label and Investigational Use Of Marketed Drugs, Biologics, and Medical Devices. Retrieved from https://www.fda.gov/RegulatoryInformation/Guidances/ucm126486.htm

FDA. (2018d). PMA Supplements and Amendments. https://www.fda.gov/medical-devices/premarket-approval-pma/pma-supplements-and-amendments

FDA. (2019). Premarket Approval (PMA). Retrieved from https://www.fda.gov/medicaldevices/deviceregulationandguidance/howtomarketyourdevice/premarketsubmissions/premarketapprovalpma/

Frattarelli, D. A., Galinkin, J. L., Green, T. P., Johnson, T. D., Neville, K. A., Paul, I. M., Van Den Anker, J. N., American Academy of Pediatrics Committee on Drugs. (2014). Off-label use of drugs in children. *Pediatrics*, *133*(3), 563–567. https://doi.org/10.1542/peds.2013-4060

Jansen, R. M. (2011). Dissemination of information on the off-label (unapproved) use of medication: A comparative analysis. *Medical Law, 30*(1), 115–132.

Representative Upton, F. H.R.6 - 21st Century Cures Act. (2016) https://www.congress.gov/bill/114th-congress/house-bill/6

Richardson v. Miller. (2000). 44 S.W.3d 1, 2000 Tenn. App. LEXIS 551 (Tenn. Ct. App. Aug. 16, 2000).

Sladen, D. P., Gifford, R. H., Haynes, D. S., Kelsall, D., Benson, A., Lewis, K., . . . Driscoll, C. L. (2017). Evaluation of a revised indication for determining adult cochlear implant candidacy. *Laryngoscope, 127*(10), 2368–2374.

Smieliauskas, F., Sharma, H., Hurley, C., de Souza, J. A., & Shih, Y. T. (2018). State insurance mandates and off-label use of chemotherapy. *Health Economics, 27*(1), e55–e70. https://doi.org/10.1002/hec.3537

Valeo, T. (2011). A Catch-22: Neurologists can prescribe off-label, but risk health insurers' denials for reimbursement. *Neurology Today, 11*(7), 28–30.

Van Allen, E. M., Miyake, T., Gunn, N., Behler, C. M., & Kohlwes, J. (2011). Off-label use of rituximab in a multipayer insurance system. *Journal of Oncology Practice, 7*(2), 76–79.

Worldometers. (2019). Worldometers: U.S. Population. Retrieved from U.S. population website: http://www.worldometers.info/world-population/us-population/

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

2

Adult Cochlear Implant Candidate Selection

René H. Gifford

INTRODUCTION

Cochlear implant criteria have evolved rapidly since the Food and Drug Administration (FDA) first approved multichannel cochlear implants for adults in 1985. Candidacy criteria vary with patient age (due to Medicare requirements), etiology, insurance coverage, implant manufacturer, and even across implants within a manufacturer (e.g., Nucleus Hybrid-L24 and MED-EL EAS). Further obscuring the determination of candidacy is the presence of overlapping indications with cochlear implants, hearing aids, osseous integrated auditory prostheses, middle ear implants, and shorter electrode, *atraumatic* cochlear implants for hearing preservation. With all these variables at play, the selection of appropriate cochlear implant candidates can be a complicated process—even for the most knowledgeable members of a cochlear implant team. On the other hand, clinicians who do not regularly work with cochlear implants may not be fully aware of how many patients can potentially benefit from this technology.

There are a number of aspects requiring consideration in the process of adult cochlear implant candidate selection. Although many are related to the audiologic evaluation, including audiometric and speech recognition testing, there are also medical, radiologic, and psychological issues requiring careful consideration.

This chapter discusses the process of adult cochlear implant candidate selection, including aspects to be considered from the perspective of the audiologist, speech/language pathologist, social worker and/or psychologist, as well as the medical/surgical team.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

AUDIOLOGIC EVALUATION

Assessment of Hearing Status

Virtually all cochlear implant evaluations begin in the audiology clinic. By the time an adult patient is referred for a cochlear implant evaluation, they have

likely already been followed for a number of years by an audiologist for hearing aid fittings. Additionally, long-standing hearing aid users have also likely been seen by an otolaryngologist at some point in their journey as hearing aid medical clearance (or a signed waiver) was required by the FDA prior to December 2016. Thus, by the time an adult patient arrives for a cochlear implant evaluation, s/he is typically aware that hearing aids are not providing adequate benefit for successful communication and is ready to take the next step. From a professional perspective, this is generally a much different experience from that commonly faced by the rehabilitative audiologist recommending hearing aids—where denial and hesitation are often the norm.

Despite the fact that most patients present to the cochlear implant evaluation with prior audiograms, it is recommended that comprehensive audiometric testing be completed. This includes audiometric thresholds via air-conduction for octave frequencies 125 through 8000 Hz as well as bone conduction for at least 500 through 400 Hz, immittance, and standard speech audiometry, including ear-specific speech reception thresholds and word recognition with recorded stimuli. Obtaining thresholds at 125 Hz is particularly important given that the professions of otology and audiology are increasingly aware of minimally traumatic surgical techniques and low-frequency hearing preservation following cochlear implantation (Carlson et al., 2011; Roland, Gantz, Waltzman, & Parkinson, 2016; Wanna et al., 2018; Woodson, Reiss, Turner, Gfeller, & Gantz, 2010); thus, having this baseline information is critical if we are to investigate the presence of residual acoustic hearing in the implanted ear following surgery. Although OAEs are a valuable part of diagnostic audiology, they are generally not included in most adult implant evaluation protocols. The reason is that adult patients presenting for a cochlear implant evaluation will generally have been wearing hearing aids for a number of years. In fact, limited benefit from "appropriately fitted hearing aids" is listed as a requirement for determination of candidacy by all three cochlear implant manufacturers (Cochlear Americas package insert, Advanced Bionics package insert, MED-EL package insert). Thus, even if an adult had present OAEs at lower frequencies in the past, the use of amplification has been shown to be associated with secondary loss of OAEs per long-term use (Deltenre et al., 1999). However, should there be any concerns about inconsistencies in diagnostic results or if the patient has precipitously sloping high-frequency hearing loss, OAEs could be easily integrated into the preoperative evaluation.

Cochlear Implant Criteria: Audiometric Thresholds

As discussed in Chapter 1, adult cochlear implant criteria differ across implant manufacturers. Audiometric criteria for implantation also differ across the manufacturers as well as across insurance carriers. For example, Advanced Bionics and MED-EL specify bilateral severe-to-profound sensorineural hearing loss for adult implant candidacy. On the other hand, both Cochlear and Medicare (CMS, 2005) specify bilateral moderate-to-profound sensorineural hearing loss—recognizing that individuals with sloping hearing losses may not derive significant benefit from amplification allowing for successful communication. A common question posed by clinicians focuses on determination of candidacy for an individual who may meet the more relaxed audiometric criteria for Cochlear and Medicare, but who may actually wish to pursue implantation with either Advanced Bionics or MED-EL. Though every implant program and team should develop their own protocol to address such matters, it is generally the case that if a patient meets implant candidacy criteria for any of the manufacturers, the patient is free to choose an implant system that meets their needs. As stated in Chapter 1, FDA-labeled indications are provided as *guidelines* for device use and should not supersede professional clinical judgment.

STUDENTSHUB.com Uploaded By: tuka abuzneid

SPEECH-RECOGNITION TESTING

Sensation Versus Perception

We were taught in Psychology 101 that there is a distinct difference between sensation and percep-

tion. Sensation is a lower-order sensory process by which an individual detects the presence of a stimulus in his or her environment. The audiogram is a perfect example of *sensation* in that audiometric thresholds represent a patient's *sensation* or detection of pure-tone stimuli. Perception, on the other hand, involves higher-order processing in that the sensed stimulus is sent to the brain for interpretation of derived meaning. Speech recognition testing is a perfect example of *perception* in that the patient's score represents the perception, recognition, and understanding of the presented speech stimulus.

In audiology, we have historically placed great emphasis on the audiogram, or the patient's *sensation* of tonal stimuli. Although the audiogram serves as an excellent diagnostic tool, it provides limited information because it does not provide any data about the patient's functional *perception* of speech, and hence, his or her ability to communicate in everyday life. We have all heard patients report that they can hear speech (sensation), but that they just cannot understand speech (perception). Furthermore, it is well recognized that similar audiograms can yield very different functional outcomes with respect to speech perception abilities; thus, it is critical for us clinicians to consider a patient's complete audiologic profile so that we avoid the trap of failing to look *beyond* the audiogram.

Speech-Perception Metrics

Much of the preoperative assessment in this section can also be found in the Minimum Speech Test Battery (MSTB). The MSTB was originally developed in 1996 when representatives from the American Academy of Otolaryngology-Head and Neck Surgery, the American Academy of Audiology, and an experienced group of clinicians/scientists from the cochlear implant manufacturers met to determine the MSTB recommended for audiologic cochlear implant candidacy and for longitudinal assessment of postoperative performance. The MSTB manual, which was revised in 2011 and is frequently referenced throughout this book, can be downloaded for free at http://www.auditorypotential.com/MSTB_Nav.html.

Recorded Materials

A central component of all adult cochlear implant evaluations is the behavioral assessment of speech recognition. Many individuals with hearing loss report that in order to "hear," they must be able to "see" the talker, that is, they rely heavily—if not entirely—on visual cues, such as lip reading and more global nonverbal communication. Thus, in order to gain an understanding of an individual's auditory-based, speech recognition abilities, stimuli must be presented without visual cues.

The most important aspect surrounding the administration of speech stimuli involves the use of recorded speech materials. The use of recorded materials for speech recognition assessment has been recommended since 1949 when the Father of Audiology, Raymond Carhart (1949), suggested the use of phonograph recordings to increase test stability across conditions. Unfortunately, however, over two-thirds of audiologists report that they routinely use monitored live voice (MLV) for administration of speech recognition materials (Martin, Champlin, & Chambers, 1998; Medwetsky, Sanderson, & Young, 1999). It is unclear, however, whether this estimate included audiologists involved in determining cochlear implant candidacy.

Roeser and Clark (2008) examined word recognition performance obtained with recorded materials as compared with MLV for 32 ears. As shown in Figure 2–1, Roeser and Clark reported that word recognition scores for MLV and recorded stimuli were significantly different for 23 of the 32 ears (or 72% of the population). In fact, the difference between the scores obtained via MLV and recorded stimuli was as high as 80-percentage points; thus, these data confirm the critical need for the elimination of MLV presentation particularly for the assessment of cochlear implant candidacy. Currently, Cochlear Americas, MED-EL, and CMS specify the use of recorded stimuli for the implant evaluation. The prevalence of recorded materials available on compact discs or digitized for transmission from the output of the computer sound card directly to the stand-alone audiometer or computer-based audiometer makes for simple and inexpensive use as well as presentation of recorded stimuli.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

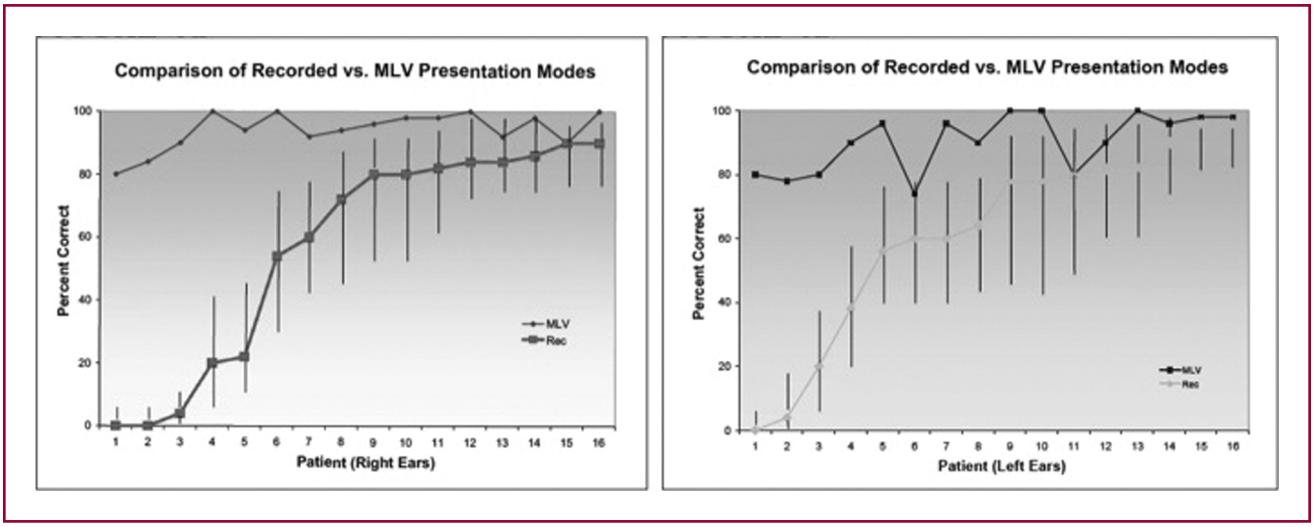


FIGURE 2–1. Comparison of word-recognition scores for the right ear (**A**) and left ear (**B**) using monitored live voice and recorded presentation for 16 patients. The ranges shown for the recorded presentations are the 95% confidence levels predicted from the binomial tables of Raffin and Thorton (1980). Reprinted with permission.

Presentation Level

A second critical aspect of speech recognition testing for preoperative cochlear implant evaluation involves the presentation level of the recorded speech stimuli. For many years, the accepted presentation level for the stimulus was 70 dB SPL because this was thought to be necessary in order to provide audibility for individuals with severe-to-profound hearing loss. The problem with using a presentation level of 70 dB SPL is that it is not representative of average, conversational-level speech. In a study funded by the Environmental Protection Agency, Pearsons, Bennett, and Fidell (1977) reported that average conversational speech was 60 dB SPL, and that 70 dB SPL was (1) representative of raised level or loud speech and (2) not sustainable from a talker's perspective for an extended period of time (Pearsons, Bennett, & Fidell, 1977). A number of studies have evaluated speech perception performance for both pre-implant (Alkaf & Firszt, 2007) and postimplant recipients (Firszt et al., 2004; Skinner, Holden, Holden, Demorest, & Fourakis, 1997) at multiple presentation levels including 50, 60, and 70 dB SPL. They found that postoperative performance for both 60 and 70 dB SPL was essentially identical but that *preoperative* performance was significantly poorer for 60 dB SPL as compared with 70 dB SPL. Thus, presentation levels of 70 dB SPL are not appropriate for determining implant candidacy because this: (1) puts the individual at a disadvantage because it is not representative of average conversational levels in the real world, (2) potentially inflates the listener's speech recognition performance, and (3) may disqualify an individual from candidacy who could derive significant benefit from cochlear implantation (and who is significantly struggling in average conversational levels). Indeed, the best practices recommendations as included in the 2011 MSTB manual have included the use of recorded speech materials presented at 60 dBA[1] for assessment of speech recognition performance for pre- as well as postimplant testing.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

[1]The use of A-weighting for sound-level-meter measurements is recommended due to the fact that linear weighting, which is implied in an SPL reference unless otherwise specified, provides noisier recordings due to flat frequency response through the lower-frequency region. In contrast, the A-weighted frequency response rolls off for lower frequencies having reached 20 dB of attenuation, relative to pass-band, at 100 Hz.

Speech Recognition Test Materials for Determining Candidacy in Adults

A variety of speech recognition materials are available to be used in the assessment of cochlear implant candidacy including monosyllabic words, sentences, and sentences in noise. With respect to adult cochlear implant candidacy, the 1996 MSTB committee (Nilsson et al., 1996) recommended that speech recognition performance be assessed with both monosyllabic words (consonant nucleus consonant [CNC] words) (Peterson & Lehiste, 1962) and the Hearing in Noise Test (HINT) sentences (Nilsson, Soli, & Sullivan, 1994) presented in quiet and in a fixed level noise background. The revised MSTB recommends the use of CNC words and AzBio (Spahr et al., 2012) sentences as there is evidence that the HINT sentences suffer from ceiling effects, even for some preoperative patients who struggle with communication and derive benefit from cochlear implantation (Gifford, Shallop, & Peterson, 2008). The MSTB also recommends the administration of AzBio sentences in quiet and noise as well as the Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) test (Etymotic, 2005; Killion, Niquette, Revit, & Skinner, 2001).

Despite these recommendations for assessment both in quiet and noise, current adult cochlear implant candidacy in the United States, with respect to speech recognition performance, is based *solely* on sentence recognition in a *quiet background*. The use of words, sentences in quiet, and sentences in noise provides information on the individual's performance in a variety of listening conditions, as well as verification of subject performance via cross-checking across the different speech recognition materials and the known interrelationship of individual performance on those measures. However, as a field, we may be moving toward the use of a monosyllabic word criterion for determining implant candidacy. At the time of chapter preparation, both Cochlear and MED-EL were completing FDA approved clinical trials investigating the efficacy of a word-based criterion up to 40% correct in the implanted ear. Further, labeled indications for the Nucleus Hybrid-L24 and MED-EL EAS systems are both based on monosyllabic word recognition (see Table 1-3). As mentioned in Chapter 1, sentence recognition scores conflate auditory peripheral processing (bottom-up processing) and higher level neurocognitive processing (top-down processing). Though native speakers will have some contextual advantages for monosyllabic word tests using inherently learned statistical language principles regarding which phonemes are most likely to be paired (e.g., phonotactic probability), this task still represents a more accurate reflection of a listener's auditory resolution of incoming spectral and temporal cues.

As with the other previously discussed aspects of implant candidacy, each manufacturer outlines a slightly different set of indications found in the FDA-approved Physician's Package Insert labeling for each device. At the time of chapter preparation, Advanced Bionics specified HINT sentence recognition up to 50% in the best-aided condition. Cochlear Americas specified sentence recognition up to 50% correct in the ear to be implanted and up to 60% in the best-aided condition. MED-EL listed HINT sentence recognition up to 40% correct in the best-aided condition. Lastly, CMS criteria were also outlined independently to include sentence recognition up to 40% correct in the best-aided condition.

Hearing Aid Verification

Prior to the consideration of which speech metric should be used to determine candidacy, we must first verify that the patient has appropriately fitted hearing aids. This is particularly important since limited benefit from appropriately fitted hearing aids is specifically listed as a requirement for implant candidacy by all implant manufacturers.

Verification of hearing aid settings may mean different things to different clinicians; however, there are clearly defined practice guidelines for verifying hearing aid settings. In 2006, the American Academy of Audiology published the "Guidelines for the Audiologic Management of Adult Hearing Impairment" (Valente et al., 2006). These guidelines state that "prescribed gain from a validated prescriptive method should be verified using a probe-microphone approach that is referenced to ear canal SPL." What this means is that functional gain measures are *not* appropriate for verification of hearing aid settings as part of

STUDENTS-HUB.com Uploaded By: tuka abuzneid

the candidacy selection process. Although aided sound field thresholds provide information about audibility of low-level stimuli, they do not provide data regarding audibility for the average conversational level speech, which is a benchmark of successful communication.

There are many options for the use of probe microphone measures in the verification of hearing aid settings, most of which are not only beyond the scope of this book but could also comprise an entire book on their own. One consideration for probe-microphone measurements that is closely related to the implant candidacy process, however, is the choice of level used for the verification of gain and/or output of the hearing aid. As mentioned previously, the MSTB recommends a presentation level of 60 dB SPL for speech stimuli used in the determination of implant candidacy; thus, it would follow that the stimulus used for hearing aid verification, whether it be speech or a speech-like signal, should also be 60 dB SPL. Verification at other levels may also be incorporated by individual implant program protocols; however, 60 dB SPL should be considered the level used in the verification of hearing aids and is considered the minimum required for best practices in hearing aid verification prior to determining implant candidacy. Despite the efficacy of cochlear implantation, it is of critical importance that candidacy be determined with appropriately fitted hearing aids to ensure that the least invasive treatment option be determined for all patients.

Testing Conditions

The testing conditions for determining cochlear implant candidacy are not widely agreed upon among clinicians. All implant manufacturers, as well as Medicare, use the term "best-aided condition" for determination of implant candidacy. Only one of the manufacturers, Cochlear Americas, specifically states different performance criteria for the ear to be implanted as compared with the best-aided listening condition, allowing for binaural summation and/or asymmetry between the ears. The "best-aided condition" is subject to interpretation. In the case of asymmetric hearing loss and/or speech recognition performance across the ears, the best-aided condition may be a gross overestimation of performance as compared with performance for the proposed ear to be implanted. Let's consider this within the context of vision. Eyeglass prescriptions and ophthalmological surgical decisions are based on individual eye performance. Imagine an optometrist or ophthalmologist telling an individual with asymmetric vision that visual correction could not be attempted because the better eye was "good enough."

A number of peer-reviewed papers (e.g., Firszt, Holden, Reeder, Cowdrey, & King, 2012; Firszt, Reeder, Holden, & Dwyer, 2018; Sladen et al., 2017), a consensus document (Fabry Firszt, Gifford, Holden, & Koch, 2009), and the adult MSTB (MSTB, 2011) have recommended individual ear testing for postoperative assessment of performance; thus, it would follow that we should be assessing individual ear performance preoperatively, as well. Given the individual ear performance indications for Hybrid-L24 as well as MED-EL EAS and SSD, and the ongoing clinical trials investigating revised indications for adult cochlear implantation, it is likely that more emphasis will be placed on individual ear performance, and that ultimately, candidacy will be determined based on the ear to be implanted.

The revised adult MSTB (MSTB, 2011) does not specifically list recommendations for testing conditions to be used either pre- or postoperatively; thus, it is important for each cochlear implant program to determine a protocol based on the goals for preoperative testing. Given that it is reasonable to assume speech perception performance will be assessed for the CI-alone condition postoperatively, it follows that individual ear performance must also be quantified preoperatively in order to have a baseline against which future gains in performance can be compared. It may be the case that not all speech metrics are presented to each ear individually, as well as in the best-aided condition during the preimplant workup; *but it is of critical importance for determining individual implant efficacy that individual ear performance, as well as the best-aided condition, be assessed for at least one speech metric*. Of course this does not apply to ears for which there is no behavioral hearing—and hence no hearing aid can be worn for preoperative assessment.

STUDENTSHUB.com Uploaded By: tuka abuzneid

Testing Setup and Calibration

Testing for adult cochlear implant candidacy requires a sound-treated booth or room, as well as a calibrated audiometer, loudspeaker, compact disc player, or computer[2] with sound card or MP3 player, and a comfortable chair for the patient. The sound-treated room should meet ANSI S3.1, American National Standard for Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI, 1999). In addition to minimizing ambient noise levels, it is important to minimize reflectant surfaces in the sound booth as reverberation affects speech recognition, particularly for individuals with hearing loss.

The adult MSTB recommends that the loudspeaker be placed at a distance of approximately 1 m (or 39.4 inches) from the listener with the listener seated at or close to the center of the room. For that reason, the minimum room size required for preoperative implant candidacy evaluation is 1.83 × 1.83 m (6 × 6 feet). The reasoning behind the 1-m distance recommendation is related to the near/far-field boundary. When a signal is presented via a loudspeaker, there is an associated near field and far field. In the near field, large SPL changes are observed for small changes in distance from the loudspeaker. It is for this reason that sound-field testing is typically completed with listeners placed between the near/far-field boundary. For most sound booths, the distance between the listener and the loudspeaker tends to be approximately 1 m (Dirks, Morgan, & Wilson, 1976) and should not be close to the walls of the room or any other reflective surfaces.

The loudspeaker should be positioned at the level of a typical seated listener's head (approximately 39 inches [86 cm] from the floor) at 0° azimuth. Figure 2–2 shows an example of an adult cochlear implant recipient seated in an audiometric sound booth meeting all of the above-listed criteria.



FIGURE 2–2. An adult cochlear implant recipient is seated at a distance of just over 1 meter from the speaker for speech recognition testing.

Calibrating Speech Stimuli: Input and Output Calibration

Calibration of speech stimuli for presentation in the free field requires that both the input and output of the audiometer be calibrated. Generally a calibration tone at 1000 Hz is provided along with the stimuli to calibrate the *input level* to the audiometer. To do this, set the audiometer to External A or B, corresponding to the input port used to connect to the CD player, MP3 player, or computer.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

[2]Should your clinic decide to upload digitized speech stimuli to a computer hard drive, it is still important to be cognizant of the site licenses required for individual speech tests. For example, if your clinic has three sound booths, then three copies of the material would still need to be purchased

The transducer is set to *speaker*, although it is not critical at this point as only the *input* is being calibrated; however, to avoid presentation of a high-level stimulus through the speaker—which, depending on the dial setting of the audiometer can be startling or even sufficiently loud to approach discomfort—it is recommended that the dial be set to a low level such as –10 dB HL. Next, press the *interrupt* or *stimulus* button to present the input calibration tone through the audiometer. Once the calibration tone is on, adjust the sensitivity dials for External A and/or B to ensure that the VU meter is set to 0 or just below. This is done to avoid distortion and clipping of the input signal.

Once the input signal is calibrated and the sensitivity dials of External A and/or B are set, these dials should *not* be adjusted further during the calibration and presentation process. From this point forward, calibration of the *output signal* to the desired presentation level is completed by manipulating the audiometer dial setting.

Output calibration requires the use of a sound level meter (SLM). The SLM microphone can be placed on a stand or suspended from the ceiling via cable so that the microphone is placed at the position of a typical listener's head when the listener is seated in a chair. This MSTB manual recommends that this height be approximately 39 inches (86 cm) from the floor, which also corresponds to the recommended level of the loudspeaker. This method of calibration is referred to as the substitution method as the calibration does not involve probe tube microphone placement for the actual patient but instead involves the substitution of the SLM microphone at the approximate placement of the listener's head. Figures 2–3 and 2–4 display



STUDENTS-HUB.com Uploaded By: tuka abuzneid

FIGURE 2–3. SLM microphone placement on a stand.



FIGURE 2–4. SLM microphone placement suspended from the ceiling via an extension cable.

possible SLM microphone placements: on a stand or suspended from the ceiling via extension cable, respectively. The former method (see Figure 2–3) is recommended for clinics in which daily access to a SLM is not possible. The latter method (see Figure 2–4) is a convenient way to achieve daily calibration of the speech stimuli without having to move SLM equipment in and out of the booth. The use of an extension cable also allows for (1) placement of the SLM in the control room next to the audiometer for easy calibration without having to go back and forth between the control room and the booth until the desired output level is achieved, and (2) daily calibration and/or calibration prior to conducting sound field speech recognition testing for every patient. An extension cable can be used in conjunction with a mic stand so that the SLM can be located in the control room next to the clinician; however, this is not the norm.

For sound field calibration, a *calibration noise* accompanies speech stimuli on CD or via WAV or MP3 stimuli. Note that it is not appropriate to use a calibration tone for calibration in the sound field due to the presence of standing waves. Set the SLM to A weighting and fast response and adjust the audiometer dial in 1-dB increments until the display reads 60 dBA. It is at this dial setting, and accompanying EXT A/B sensitivity dial setting, that the speech stimuli will be presented at 60 dBA, which is the MSTB recommended presentation level. Note that the audiometer dial level and the SPL will likely not be equivalent. That is expected and has more to do with the input sensitivity and sound card specifications.

In an ideal clinical setting, speech stimuli presented in the sound field would be calibrated prior to each presentation or testing session. Unless the clinic owns a SLM dedicated for sound field calibration in a particular sound booth, this is not a realistic option. The next best option would be to complete daily calibration. Any schedule that does not involve calibration prior to each testing session runs the risk of inaccuracy. Using inaccurate presentation levels could lead to inappropriate recommendations regarding cochlear implant candidacy involving either under- or overqualifying patients. This is particularly true if a clinic is using digitized/computerized speech stimuli. The reason is that the output volume for the computer sound card directly influences the input to the audiometer and the level of the corresponding loudspeaker. For clinics using digitized/computerized stimuli, it is recommended that the master volume on the computer always be set to maximum. The computer volume setting should be checked prior to each and every testing session and would be best to not be adjusted. In order to ensure that your patient isn't startled with audible computer alerts regarding calendar invitations and email notifications, deactivating all audible alerts is recommended.

For clinics where daily access to a SLM is not possible, it should be noted that there are a number of accurate SLM applications that can be run from a smartphone. What is critical is that the clinician test the accuracy of the SLM app against the calibrated SLM. Once this is completed, daily

STUDENTS-HUB.com Uploaded By: tuka abuzneid



FIGURE 2–5. SLM reading matching the SLM app reading.

calibration is possible using the phone in your pocket as shown in Figure 2–5.

Time Allotted for Preoperative Evaluation

How much time should be allotted for a cochlear implant evaluation or workup appointment? This depends on an individual clinic protocol. Some clinics may choose to follow MSTB recommendations for pre-implant workups but only include the minimum recommended testing schedule due to time, space, and/or personnel restrictions. Other clinics may choose to incorporate the MSTB recommendations but also obtain supplemental information during the workup with additional tests, metrics, and/or conditions. Using the MSTB's minimum recommended schedule as shown in Table 2–1, the approximate times for completion of each audiologic procedure were obtained from a time study of practice patterns for standard audiometry (Tucker, 2001), as well as for hearing aid verification (Busen & McCarthy, 2010). Time estimates for aided speech perception testing were obtained from the MSTB document as well as author experience. Table 2–1 also provides time estimates for each of the procedures outlined in the MSTB. The estimates for audiometry and hearing aid verification reflect mean time estimates (in minutes) plus two standard deviations, as 95% of the expected values should fall within this range assuming a normal distribution. The time estimates for aided speech perception reflect the expected range of time (in minutes) needed for administration and scoring. Using the estimates provided in Table 2–1—assuming that just one of the speech recognition measures was administered via left HA, right HA, and bilateral HA, the total time required for audiometric testing, hearing aid verification, and aided speech perception testing would take approximately 94.4 to 106.4 minutes. This time does not take into account the need to reprogram hearing aids should the patient's own hearing aid settings not be providing target audibility.

Though this may seem like a lot of time for testing, it is reasonable to err on the conservative side. The reason is that the severity of hearing losses observed with preimplant patients often

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 2–1. Minimum Recommended Schedule of the Minimum Speech Test Battery (Adult Candidacy Workup Checklist)

Comprehensive audiologic evaluation		
Audiometric thresholds (AC & BC)	AC: 125 to 8000 Hz BC: 500 to 4000 Hz	36.4 minutes
Speech audiometry	SRT and word recognition, recorded stimuli	
Tympanometry	226-Hz probe	6.8 minutes
Acoustic reflex thresholds (i.e., middle ear muscle reflexes)	Ipsilateral and contralateral: 500–4000 Hz	11.2 minutes
Hearing aid (HA) verification		
Electroacoustic verification and real ear measures	Speech or speech-like stimuli at 60 dB SPL	22.0 minutes
Aided speech-recognition testing		
Recorded stimuli, 60 dB SPL, best-aided condition[a]		
CNC	One 50-item list	3 to 5 min (9 to 15 minutes if administered in each condition)
AzBio sentences in quiet	One 20-sentence list	3 to 5 min (9 to 15 minutes if administered in each condition)
AzBio sentences in fixed SNR noise	One 20-sentence list	3 to 5 min (9 to 15 minutes if administered in each condition)
BKB-SIN test	One paired list	3 to 5 min (9 to 15 minutes if administered in each condition)
Administration of questionnaires		
Expectations questionnaire(s)	Administered prior to appointment	No additional appointment time
Preimplant administration of outcome measures and/or quality-of-life questionnaire(s)	Administered prior to appointment	No additional appointment time

[a]At least one metric should also be administered in the right-HA and left-HA conditions

Note. *CNC* consonant nucleus consonant; *Air conduction (AC)*; Bone conduction (BC); *SRTs* speech-reception thresholds; *BKB-SIN* Bamford-Kowal-Bench-Sentence-in-Noise.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

necessitates written instructions on a large computer monitor facing the patient or by writing instructions on paper or dry erase board. For this reason, it is a good idea for each clinic to prepare simple written instructions for audiometry and speech perception testing that can be used at each cochlear implant evaluation.

In addition to the 94.4 to 106.4 min for testing completed during a cochlear implant evaluation, the clinician must allocate a significant portion of time for reviewing test results, questionnaires, counseling, and introduction of the available cochlear implant systems. Should the clinician have to type or write to the patient, this time is

lengthened considerably; thus, it is reasonable to allocate approximately 2 to 3 hours for a cochlear implant evaluation. Given this lengthy process, clinic space restrictions, and reimbursement concerns, as a field, we will need to streamline our preoperative candidacy assessments. Moving toward a monosyllable-based criterion would move the field forward toward a greater clinical efficiency as it would minimally require monosyllabic word recognition in each ear alone and the bilateral aided condition. This would cut the minimum speech recognition battery to just 9 to 15 minutes (Table 2–1), with overall booth testing and HA assessment time estimated maximally at 85.4 to 91.4 minutes.

SUBJECTIVE EVALUATION OF ADULT PREIMPLANT PERFORMANCE

Evidence-based practice (EBP) is gaining increasingly more attention in clinical patient care as insurance companies require proof of treatment efficacy for coverage purposes. EBP in audiology has largely been associated with hearing aid fittings; however, EBP plays an active role in the preimplant evaluation and postoperative fitting and assessment of patients with cochlear implants, as well. Objective measures of pre- and/or postimplant speech perception and subjective assessments of perceived performance and/or benefit may not be in good agreement with one another (Holder et al., 2018; Wackym, Runge-Samuelson, Firszt, Alkaf, & Burg, 2007). One likely explanation is that the laboratory conditions assessed in the audiometric test booth may not truly reflect real-world listening conditions. Furthermore, subjective assessment instruments can also serve to validate the efficacy of a particular treatment option, such as cochlear implantation. Although we recognize the efficacy of cochlear implantation with respect to restoration of hearing and speech recognition, we do not routinely assess the effect of cochlear implants on a recipient's social and/or emotional welfare, or the more global effect on one's quality of life. On another level, the use of subjective measures during the *preoperative* assessment can provide an element of information that is not necessarily contained within the more objective scores of speech recognition. There are a number of instruments used to assess subjective performance, and/or quality of life following cochlear implantation.

One of the most commonly used questionnaires in both hearing aid and cochlear implant clinics is the Speech, Spatial, and Qualities (SSQ) questionnaire (Gatehouse et al., 2004) or its 12-item analog, the SSQ12 (Noble, Jensen, Naylor, Bhullar, & Akeroyd, 2013). The original SSQ is a 49-item questionnaire gauging information about one's hearing abilities and experiences for speech communication, spatial hearing, and quality of speech and sounds. The SSQ uses an 11-point, visual analog scale for which 0 represents a number of negative connotations such as *not at all*, *jumbled*, *not at all*, and *lots of effort*; 10 represents a number of different positive connotations such as *perfectly*, *natural*, *not jumbled*, or *no effort*. The respondent is asked to indicate on the numerical scale the number that best expresses his or her hearing experience for each of the 49 scenarios. The SSQ12 was validated to provide a streamlined version of the SSQ rendering it much more clinically applicable. The same three categories are gauged, but with only 3 to 5 questions for each of the categories.

In addition to the SSQ and SSQ12, there are a number of additional questionnaires being used, though to a lesser degree in the typical cochlear implant clinical environment. Although the 24-item Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995) was designed to gauge degree of benefit following hearing aid fittings, due to the ease of administration and the relative brevity of the questionnaire, it is also used in some cochlear implant programs, as well. The APHAB self-assessment scale evaluates listening difficulty experienced in four areas: ease of communication, background noise, reverberation, and aversiveness of sound; thus, the difference in listening difficulties found pre- and postimplant provides an index of the benefit associated with cochlear implantation.

The Client-Oriented Scale of Improvement (COSI) (Dillon, James, & Ginis, 1997) is a clinical assessment instrument developed by National

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Acoustic Laboratories for evaluating individually determined outcomes following amplification. The COSI can be easily adapted for use with cochlear implant recipients as the patient can identify listening situations that he or she would like improvement with cochlear implants. Although the COSI is a great tool for use with patients, it is limited in its across-patient comparison due to the individual nature of the instrument.

The Nijmegen Cochlear Implant Questionnaire (NCIQ) (Hinderink, Krabbe, & Broek, 2000) is a 60-item, quality-of-life instrument designed for use with adult cochlear implant recipients. The NCIQ assesses six domains including basic sound perception (e.g., environmental sounds), advanced sound perception (e.g., modulation of one's own voice, speech intelligibility), speech perception, self-esteem, activity, and social interactions. The NCIQ was designed for administration both at pre- and postimplant assessments.

The Cochlear Implant Quality of Life (CIQOL) questionnaires (McRackan, Hand, Velozo, & Dubno, 2019; McRackan, Hand, Velozo, & Dubno, in press) were developed following the Patient-Reported Outcomes Measurement Information System (PROMIS) and COnsensus-based Standards for the selection of health status Measurement INstruments (COSMIN) guidelines, which include a combination of qualitative (e.g., focus groups, cognitive interviews) and quantitative (e.g., confirmatory factor analysis and item response theory) methodology. There are two available versions of the CIQOL (McRackan, Hand, Velozo & Dubno (in press)): 1) the CIQOL-35 Profile includes 35 items gauging QOL in 6 unidimensional domains (communication, emotional, entertainment, environmental, listening effort, and social), and 2) the CIQOL-10 Global is a shorter version including just 10 items that provide a global evaluation of CI user QOL, but no domain-specific information. All CIQOL-10 Global items are included in the CIQOL-35 profile; thus a global QOL score can also be determined from responses to the CIQOL-35 instrument. The two CIQOL instruments are available to download at education.musc.edu/CIQOL.

The 25-item Cochlear Implant Function Index (CIFI) (Coelho, Yeh, Kim, & Lalwani, 2009) is a self-assessment instrument that was designed and validated for use with adult cochlear implant recipients. The CIFI evaluates an individual's reliance on visual cues, use of the telephone, communication at work as well as hearing in noise, in groups, and in large-room settings. As with the other instruments, the CIFI is recommended for administration both pre- and postimplant.

The 18-item Glasgow Benefit Inventory (GBI) (Robinson, Gatehouse, & Browning, 1996) was developed to gauge patient benefit derived specifically from otorhinolaryngologic (ORL) surgical interventions. Specifically, the GBI defines patient benefit as the change in one's health status directly resulting from the procedure. The GBI questions were written to be independent of any particular diagnosis or intervention; thus, the degree of "benefit" across different ORL procedures could be compared. The inherent flexibility of the GBI can also be viewed as a weakness because it does not specifically address aspects that may be of interest to those undergoing cochlear implantation. The GBI would be administered postoperatively with 18 questions addressing the patient's state following the procedure such as, "Since your operation/intervention, do you have more or less self-confidence?" or "Since your operation/ intervention, do you feel more or less confident about job opportunities?" Responses to GBI questions are based on a 5-point Likert scale ranging from a large decline to large improvement in health status.

The Glasgow Hearing Aid Benefit Profile (GHABP) (Gatehouse, 1999) was designed to quantify hearing aid benefit as related to situations in which hearing-related handicap most likely exists. It includes assessment of difficulty and the benefits of a hearing aid for four fixed communicative situations including (1) listening to the television with family or friends when the volume is adjusted to suit other people, (2) having a conversation with one other person when there is no background noise, (3) carrying on a conversation in a busy street or shop, and (4) having a conversation with several people in a group. In addition to these four fixed situations, the GHABP allows for the patient to identify up to four additional situations in which he or she feels it is important to be able to hear as well as possible. Clinicians employing the GHABP in their Hearing Aid Program may find it also useful to use the

STUDENTS-HUB.com Uploaded By: tuka abuzneid

GHABP in their Cochlear Implant Program with some modifications to the language to address implant(s) over hearing aid(s).

The Hearing Handicap Inventory for Adults (HHIA) (Newman, Weinstein, Jacobson, & Hug, 1990) and Hearing Handicap Inventory for the Elderly (HHI-E) (Ventry & Weinstein, 1982) both include 25 questions designed to gauge functional handicap resulting from hearing loss. Respondents answer "yes" (4 points), "sometimes" (2 points), or "no" (0 points) to questions such as *Does a hearing problem cause you to use the phone less often than you would like?* and *Does a hearing problem cause you to avoid groups of people?* Although the HHIA and HHI-E were designed as screening tools to quantify functional, day-to-day hearing difficulties, these may also be used as outcome measures in a pre- versus posttreatment administration. Given that many clinics may already be using the HHIA/HHI-E in the general audiology clinic or as part of the hearing aid clinic, postimplant administration could also be implemented.

More generic quality-of-life assessment instruments are also available and are widely used in cochlear implant research, though they may also be useful in the clinical environment. Health-related, quality-of-life questionnaires can assign a numerical value to duration of life as modified by the impairments (e.g., hearing loss), functional states, perceptions, and social opportunities that can be influenced by disease, injury, treatment, or policy (Patrick & Erickson, 1993). The Health Utilities Index (HUI) Mark III (Furlong, Feeny, Torrance, & Barr, 2001) is a multidimensional instrument that assesses individual abilities on attributes including vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain. There are multiple questionnaire formats available, including self-assessment, clinician-administered, and even proxy-assessment versions. Although these tools were designed with a clinical research focus, one could reasonably incorporate such an instrument into clinical protocol for cochlear implant candidate selection and assessment of health-related changes following cochlear implantation.

In addition to questionnaires designed to track outcome measures and overall quality-of-life changes resulting from cochlear implantation, there are also a number of expectation questionnaires that can be administered preoperatively. Preimplant expectation questionnaires require a patient to document, in writing, what he or she believes cochlear implants can provide in terms of benefit. Such questionnaires can be an integral part of the preimplant evaluation because they facilitate patient-specific counseling—particularly in cases for which a patient may exhibit inappropriate expectations in his or her responses. Many clinics upload the questionnaire, along with signatures of both the patient and clinician and addressed comments, into the patient's electronic medical record. That way, the questionnaire and comments can later serve as a counseling tool should the patient express unrealistic postimplant expectations, particularly those that may differ from their preimplant responses. There are a number of available expectations questionnaires related specific to cochlear implantation (Cochlear Corporation, 2003). The "expectations questionnaires" are organized into True/False questions that all begin with the statement, "When I am using the cochlear implant . . . " Examples of the questions include *Conversation over the telephone will be easy to understand,* as well as, *I can be assured of better job opportunities because of better hearing*.

ROLE OF THE SOCIAL WORKER AND/OR PSYCHOLOGISTS IN THE DETERMINATION OF COCHLEAR IMPLANT CANDIDACY

The role of the social worker and/or psychologist in the determination of cochlear implant candidacy can be pivotal for adult recipients. Psychological evaluations are generally not routinely scheduled for adult cochlear implant evaluations as was the common practice when cochlear implants were first introduced clinically. Scheduling a visit with a psychologist and/or social worker in *select adult cases*, however, can provide valuable information for not only the cochlear implant team, but also for the patient and his or her family. For example, adult patients who were prelingually deafened, as well as individuals who have had sudden onset

STUDENTS-HUB.com Uploaded By: tuka abuzneid

profound hearing loss, are obvious populations that could benefit from a preoperative psychological evaluation and/or appointment with a social worker specially trained to work with individuals with hearing loss.

It is well known that hearing loss is associated with increased incidence of depression, social anxiety, loneliness, and overall psychological distress in the adult population (e.g., Abrams, Barnett, Hoth, Schultz, & Kaboli, 2006; Gopinath et al., 2009; Knutson, Johnson, & Murray, 2006; Nachtegaal et al., 2009;). Although cochlear implantation has been shown to significantly reduce depression and other psychosocial symptoms in individuals with hearing loss (Knutson, Murray, et al., 1998; Knutson, Schartz et al., 1991; Mosnier et al., 2015; Olze et al., 2011; Poissant, Beaudoin, Huang, Brodsky, & Lee, 2008), it is possible that an individual seeking a cochlear implant may have unrealistic expectations regarding how much the implant will improve his or her depressive symptoms; thus, it is important for the clinician to refer individuals with reported depression and social anxiety related to one's hearing loss for preoperative psychological evaluation. Though there are a number of depression screening tools available, it is recommended that each cochlear implant team consult with the psychologist and/or psychiatrist who serves on or is affiliated with the cochlear implant team for recommendations.

MEDICAL AND SURGICAL EVALUATION: IMPLANT CANDIDATE SELECTION

STUDENTS-HUB.com Uploaded By: tuka abuzneid

The cochlear implant surgeon, a specialist in otology or neurotology, plays an obviously critical role in the determination of implant candidacy. Surgeons complete a thorough preoperative evaluation in addition to being responsible for the implant surgical procedure and postoperative otologic medical care. The otologist and his or her medical team ensure that all cochlear implant candidates are up-to-date on their immunizations prior to cochlear implantation. The recommended immunization schedule for adults can be found on the Centers for Disease Control website (https://www.cdc.gov/vaccines/vpd/mening/public/dis-cochlear-faq-gen.html and includes, at a minimum, an age-specific pneumococcal vaccination. The surgeon will also review the patient's current medication list and devise a plan for the management of anticoagulant medications prior to the scheduled surgery. The surgeon will also order a preoperative evaluation to ensure that the candidate is able to undergo surgery and the associated anesthetic risk. The preoperative evaluation includes assessment of vital signs and general medical evaluation to identify the presence of health problems that may affect peri- and/or postanesthetic care.

Most implant surgeons also routinely order imaging studies, including computed tomography (CT), and/or magnetic resonance imaging (MRI), to determine cochlear patency, as well as to rule out cochlear or other temporal bone anomalies that could impact the surgical insertion of the device. Cochlear and temporal bone anomalies, however, are not necessarily contraindicated for cochlear implantation, though it is critical that the surgical team be aware of such issues. High-resolution CT using a temporal bone protocol is typically ordered for all patients having met audiologic criteria for cochlear implantation (Witte et al., 2003). MRI, on the other hand, is not always ordered for adult patients with acquired sensorineural hearing loss, with the exception of those exhibiting audiometric asymmetry. However, with improvements in MRI and subsequent image processing, we are seeing more clinical programs moving toward preoperative MRI for the adult population—sometimes in lieu of CT. Additional information regarding the value of pre- and post-implant imaging is included in Chapter 5.

The surgeon's role also includes careful review of risks associated with cochlear implant surgery and obtaining informed consent for the surgical procedure. It is not within the scope of practice of the audiologist or the speech/language pathologist to initiate the discussion surrounding surgical risk. This is not to say that it is inappropriate to discuss risk with patients should they inquire; however, it is important that we defer thorough discussion and questioning of such matters to the surgeon. For this reason, the medical/

surgical consult is typically scheduled *after* the cochlear implant evaluation and workup by the audiologist.

UTILITY OF PREDICTIVE VARIABLE FOR POSTOPERATIVE OUTCOMES

Once a patient is informed that he or she is a candidate for cochlear implantation, in-depth counseling and education is critical. This is directly within the scope of the audiologist and represents a significant portion of the cochlear implant evaluation/workup appointment. Perhaps as important as educating the patient about the function of cochlear implants and what they do, is the focus on what implants *cannot* do, such as restore "normal" hearing fidelity and auditory function. In fact, this is a good point in the counseling to review the expectations questionnaire and to reconcile any discrepancies between the patient's expected outcomes and realistic outcomes.

Perhaps the most frequent question patients ask regarding cochlear implantation is how well they will do, with respect to speech understanding, following surgery. There are a number of potential factors affecting postoperative outcomes, including age, audiometric thresholds, preoperative speech perception performance, duration of deafness, integrity of cochlear and neural structures, etiology, and surgical placement of the electrode array.

Age

Given the increased life expectancy of individuals in developed countries, and more specifically in the United States (Kochanek, Xu, Murphy, Minino, & Kung, 2011), we will undoubtedly be seeing more elderly individuals for cochlear implant candidacy evaluations (World Health Organization, 2011). Traditionally, clinicians have proceeded cautiously, recommending implants for elderly individuals with the thought that surgical and audiologic outcomes may be adversely affected by age-related issues, as well as that they are associated with lower cost utility. Recently, a number of studies have investigated the benefit associated with cochlear implantation in individuals 70 years and older (Carlson et al., 2010; Chen, Grisel, Lam & Golub, 2017; Coelho et al., 2009; Kumar et al., 2016; Olze et al., 2012; Park, Shipp, Chen, Nedzelski, & Lin, 2011; Zwolan, Henion, Segel, & Runge, 2014). These studies have shown no greater anesthetic risk and equivalent degrees of benefit for postoperative speech perception in younger implant recipients (Buchman, Fucci, & Luxford, 1999; Carlson et al., 2010). In fact, even patients in their tenth decade of life have demonstrated significant postoperative benefit for speech recognition (Carlson et al., 2010). Thus, provided that an individual has been medically cleared for surgery and does not exhibit compromised cognitive status and/or dementia, there are no major concerns about an adult patient's age at implantation in terms of negatively predicting audiologic outcomes.

Audiometric Thresholds

Audiologists and surgeons tend to place considerable emphasis on the audiogram and audiometric thresholds; however, although the audiogram represents a diagnostic measure of an individual's auditory detection or *sensation*, it does not always accurately reflect an individual's auditory function or *perception*. In a study related to hearing aid outcomes, Haplin and Rauch (2009) explained that the audiogram does not represent structural impairments that underlie word recognition ability; hence, audiograms often provide false predictions of hearing aid outcome success. In fact, there are a number of papers reporting data for hearing aid users with audiograms outside the approved candidacy criteria for cochlear implantation who subjectively report and exhibit great difficulty with hearing and communicating in real-world situations (Alkaf & Firszt, 2007; Gifford, Dorman, McKarns, & Spahr, 2007; Gifford, Dorman, Shallop, & Sydlowski, 2010; Novak, Black, & Koch, 2007; Holder et al., 2018; Firszt et al., 2018).

Despite the fact that similar audiograms do not necessarily yield similar speech perception performance, it may still seem intuitive that better preoperative audiometric thresholds would yield

STUDENTS-HUB.com Uploaded By: tuka abuzneid

higher levels of postoperative performance, but this is not necessarily the case. In fact, few studies have demonstrated a significant correlation between preoperative audiometric thresholds and postoperative speech perception performance. This is true for both the ear to be implanted (e.g., Battmer, Gupta, Allum-Mecklenburg, & Lenarz, 1995; Blamey et al., 1992; Gantz et al.,1988; Gantz, Woodworth, Knutson, Abbas, & Tyler, 1993; Waltzman, Fisher, Niparko, & Cohen, 1995) as well as the nonimplanted ear (Ching, Incerti, & Hill, 2004; Ching, Psarros, Hill, Dillon, & Incerti, 2001; Gifford et al., 2007; Potts, Skinner, Litovsky, Strube, & Kuk, 2009; also see Morera et al., 2005). This finding is contrary to both clinical intuition and the longstanding belief that a higher proportion of surviving spiral ganglion cells would likely yield higher levels of postoperative speech recognition. In fact, histopathology data from human temporal bones of individuals who had been cochlear implant recipients suggests that there is either weak to modest correlation (Kamakura & Nadol, 2016; Seyeddi, Viana & Nadol, 2014), or no correlation between spiral ganglion cell survival and postoperative speech perception performance (Fayad & Linthicum, 2006; Gassner, Shallop, & Driscoll, 2005; Nadol et al., 2001). Of course, all temporal bone studies investigating the relationship between spiral ganglion cell counts and cochlear implant outcomes include very small sample sizes and thus, much greater investigation is needed.

Preoperative Speech Perception and Duration of Deafness

As described above, we must challenge ourselves to think "beyond the audiogram" and treat the patient's overall auditory profile and functional performance. In this light, one may hypothesize that higher levels of preoperative speech perception performance would yield higher levels of postoperative performance, but this is not necessarily the case.

Rubinstein, Parkinson, Tyler, and Gantz (1999) examined a number of potential variables affecting postoperative speech recognition, including preoperative sentence-recognition scores, preoperative audiometric thresholds, duration of deafness prior to implantation, and age. Despite the array of factors analyzed in the model, Rubinstein and colleagues found that duration of deafness and preoperative sentence scores of subjects were consistently found to be the two most significant predictors of postoperative hearing outcomes when factored together in multivariate analysis. The extremes of the function, however, dominated the correlation (Rubinstein et al., 1999). For the comparison of preimplant sentence recognition with post-implant word recognition, had the preimplant scores at 0% been removed from the analysis, no correlation would exist. The reason that such a consideration is valid is that those patients scoring 0% preoperatively on CID sentences scored anywhere from 0% to 70% correct for word recognition postoperatively. In a similar vein, examining duration of deafness with postoperative word recognition, had the scores for patients with greater than 20 years of duration of deafness been removed, no correlation would exist. Similar findings have been reported by more recent analyses of patient variables and associated postoperative predictive power (Friedland, Venick, & Niparko, 2003; Leung et al., 2005; Roditi, Poissant, Bero, & Lee, 2009); thus, for a large proportion of cochlear implant candidates—those with shorter durations of deafness and scoring above 0% correct preoperatively—there are currently no definitive predictive variables for postoperative speech recognition.

Integrity of Cochlear and Neural Structures

Cochlear and neural anomalies are generally considered to be most applicable to counseling for pediatric patients; however, there are instances of adult cochlear anomalies and/or auditory neuropathy that are uncovered during the cochlear implant workup process. Any structural irregularity involving the bony labyrinth, cochlear lumen, or internal auditory canal has the potential to affect postoperative outcomes. Some common structural abnormalities that one might expect to uncover in the adult population include Mondini dysplasia, enlarged vestibular aqueduct, and

STUDENTS-HUB.com Uploaded By: tuka abuzneid

atretic internal auditory canal. All of these diagnoses would be observed via CT and/or MRI and would thus be diagnosed prior to implantation for adult candidates.

Another issue that can affect postoperative performance is auditory neuropathy. This can be a true neuropathy of the auditory branch of cranial nerve VIII, which is typically associated with other peripheral neuropathies, or an auditory neuropathy spectrum disorder (ANSD) as typically associated with pediatric diagnoses. There have been a number of reported cases of adult-onset ANSD (e.g., Berlin et al., 2010; Kumar & Jayaram, 2005; Prieve, Gorga, & Neely, 1991; Shivashankar, Satishchandra, Shaskikala, & Gore, 2003; Stuart & Mills, 2009). The underlying mechanism for late or adult-onset ANSD is not well understood. The general profile of ANSD would include variable levels of audiometric thresholds, poorer-than-expected speech recognition, absent middle ear muscle reflexes, presence of otoacoustic emissions that are incongruent with the audiogram, and presence of cochlear microphonic with either absent or abnormal auditory brainstem response (e.g., Berlin, Hood, Cecola, Jackson, & Szabo, 1993; Berlin et al., 2010; Berlin et al., 2005; Hood, 2015; Starr, Picton, Sininger, Hood, & Berlin, 1996).

A true neuropathy of the auditory nerve is important to diagnose prior to considering cochlear implantation because it will expectedly impact outcomes. The word neuropathy refers to nerve damage; thus, cochlear implantation would be contraindicated for a true case of auditory neuropathy for which there is compromised integrity of the auditory nerve. The reason is that intracochlear electrical stimulation targeting spiral ganglion cells in the modiolus would be peripheral to the site of lesion, and hence, a cochlear implant would not be effective in restoring hearing. True cases of auditory neuropathy often accompany other peripheral neuropathies and include numbness, tingling, and burning of the external ear, face, lips, tongue, and extremities. Common etiologies associated with adult cases of ANSD include Friedreich's ataxia and Charcot-Marie-Tooth disease. Should a patient present with these symptoms to the audiology clinic and she or he is not currently under the care of a neurologist, a referral should be made. Care should be exercised in recommending cochlear implantation for patients presenting with these symptoms because it can be difficult, if not impossible, to distinguish between ANSD and a true case of auditory neuropathy, the latter of which would expectedly yield poor outcomes with cochlear implantation. However, there are reports of significant hearing and communicative benefit resulting from cochlear implantation even for adults with true auditory neuropathy (Frewin, Chung & Donnelly et al., 2013; Goswamy, Bruce, Green, & O'Driscoll, 2012).

Etiology

The etiology of hearing loss for the majority of adult patients seen in an audiology clinic is largely unknown. Consequently, there is generally no concern about etiology affecting counseling for postoperative outcomes. There are, however, some etiologies that are known to potentially affect postoperative outcomes seen with adult cochlear implant recipients.

Meningitis

Although the incidence of bacterial meningitis is lower in adults than in children, it remains a leading cause of acquired sensorineural hearing loss in adults. Epidemiologic studies have reported that the incidence of bacterial meningitis exhibits a twofold increase with age from the range of 18 to 34 years, to the over-65-years population, with the mean adult incidence being in the range of 1.3 to 1.5 cases per 100,000 (Thigpen et al., 2011). The cause of hearing loss associated with bacterial meningitis is typically related to the development of labyrinthitis, loss of hair cells, spiral ganglion cell degeneration, and cochlear ossification (Lu & Schuknecht, 1994; Nadol & Hsu, 1991). It is specifically the ossification and degeneration of spiral ganglion cells that can result in bony obliteration of the cochlea, loss of auditory function, and hence, poorer postoperative outcomes.

Depending on the degree of ossification, it is possible that the surgeon may not be able to achieve a full insertion of the electrode array; thus, the patient may have a restricted number of electrodes that can be stimulated. Furthermore, it is possible that with a shallow electrode insertion

STUDENTS-HUB.com Uploaded By: tuka abuzneid

depth and spiral ganglion cell degeneration, those intracochlear electrodes may not yield much, if any, auditory stimulation. Reports of postoperative outcomes following meningitis are variable and have been reported as being significantly poorer than that of the typical adult cochlear implant recipient (Battmer et al., 1995; Blamey et al., 2013; Philippon, Bergeron, Ferron, & Bussieres, 2010; Waltzman et al., 1995). Though this certainly does not apply for all cases of meningitis, it remains an important counseling point for individuals with this diagnosis.

Otosclerosis

The pathogenesis of otosclerosis includes temporal bone dysplasia, which is often referred to as an otospongiotic or bony growth that can pervade the bony labyrinth. Cochlear implantation for patients with otosclerosis is routinely performed and is typically associated with above-average postoperative outcomes (Blamey et al., 2013; Marshall et al., 2005; Quaranta et al., 2005; Sainz et al., 2007). Due to the progression of the underlying disease process, however, there are some factors to consider with regard to postoperative outcomes. The continued progression of bony growth is known to affect the intracochlear transmission of the electrical signal, which can result in variable thresholds for stimulation, charge, and facial nerve stimulation due to current shunting (Carlson et al., 2011; Sainz, Garcia-Valdecasas, & Ballesteros 2009). Consequently, it is often the case that the number of usable electrodes decreases and/or varies over time. Variation in the number of usable electrodes has the potential to impact patient performance, overall auditory perception, and sound quality; thus, these issues should be addressed in preoperative counseling during the cochlear implant evaluation/workup appointment.

Surgical Approach and Electrode Location

There is increasing evidence that surgical approach and resultant electrode location impact cochlear implant outcomes with respect to preservation of residual hearing and intracochlear structures (O'Connell, Hunter, et al., 2016; O'Connell, Holder et al., 2017; Wanna et al., 2014;), implant only speech recognition (Carlson et al., 2011; Dalbert et al., 2016; Wanna et al., 2014), electrical charge requirements for auditory perception (Davis et al., 2016; Kang et al., 2015; Litvak, Spahr & Emadi, 2007), and electrical dynamic range (Kang et al., 2015; Litvak et al., 2007). Although this is not a known variable preoperatively, this is something that we should likely be discussing with our patients prior to surgery as this holds potential value for electrode array selection. Chapter 5 provides additional details about cochlear implant surgery, imaging, and effects of electrode location.

CONCLUSION

The opening of this chapter stated that determining cochlear implant candidacy is not a straightforward process. The determination of cochlear implant candidacy is truly a *process* that is accomplished via the collective teamwork of an interdisciplinary group of professionals. Many patients and their families are astonished at the intricacies involved in a cochlear implant workup evaluation. Given the expansion of adult cochlear implant criteria, widespread insurance coverage for bilateral implantation (see Chapters 6 and 7), and increased incidence of hearing preservation (see Chapter 6) with cochlear implantation, the implant selection process will continue to evolve. Furthermore, we will likely see an even greater role for pre- and postoperative counseling as cochlear implant criteria expand, allowing greater numbers of individuals with various degrees of hearing loss and underlying etiologies to take advantage of this technology.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

Abrams, T. E., Barnett, M. J., Hoth, A., Schultz, S., & Kaboli, P. J. (2006). The relationship between hearing impairment and depression in older veterans. *Journal of the American Geriatric Society, 54*, 1475–1477.

Alkaf, F. M., & Firszt, J. B. (2007). Speech recognition in quiet and noise in borderline cochlear implant candidates. *Journal of the American Academy of Audiology, 18*(10), 872–882.

ANSI. (1999, R2003). *Maximum permissible ambient noise levels for audiometric test rooms.* New York, NY: American National Standards Institute, S3.1-1999.

Battmer, R. D., Gupta, S. P., Allum-Mecklenburg, D. J., & Lenarz, T. (1995). Factors influencing cochlear implant perceptual performance in 132 adults. In G. M. Clark, & R. S. C. Cowan (Eds.), International Cochlear Implant, Speech and Hearing Symposium, Melbourne 1994. *Annals of Otology, Rhinology, and Laryngology* (Suppl. 166), 185–187.

Berlin, C. I., Hood, L. J., Cecola, R. P., Jackson, D. F., & Szabo, P. (1993). Does Type I afferent neuron dysfunction reveal itself through lack of efferent suppression? *Hearing Research*, *65*, 40–50.

Berlin, C. I., Hood, L. J., Morlet, T., Wilensky, D., Li, L., Mattingly, K. R., Taylor-Jeanfreau, J., . . . Frisch, S. A. (2010). Multi-site diagnosis and management of 260 patients with auditory neuropathy/dys-synchrony (auditory neuropathy spectrum disorder). *International Journal of Audiology, 49*, 30–43.

Berlin, C. I., Hood, L. J., Mortlet, T., Wilensky, D., St. John, P., Montgomery, E., & Thibodaux, M. (2005). Absent or elevated middle ear muscle reflexes in the presence of normal otoacoustic emissions: A universal finding in 136 cases of auditory neuropathy/dyssynchrony. *Journal of American Academy of Audiology*, *16*, 546–553.

Blamey, P. J., Pyman, B. C., Gordon, M., Clark, G. M., Brown, A. M., Dowell, R. C., & Hollow, R. D. (1992). Factors predicting postoperative sentence scores in postlinguistically deaf adult cochlear implant patients. *Annals of Otology, Rhinology, and Laryngology, 101*, 342–348.

Blamey, P., Artieres, F., Başkent, D., Bergeron, F., Beynon, A., Burke, E., . . . Lazard, D. S. (2013). Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants: An update with 2251 patients. Audiology & Neurootology, 18, 36–47.

Buchman, C. A., Fucci, M. J., & Luxford, W. M. (1999). Cochlear implants in the geriatric population: Benefits outweigh risks. *Ear, Nose & Throat Journal*, *78*, 489–494.

Busen, J., & McCarthy, P. (2010). *Probe-microphone measurements: Commonly used or neglected*? Presented at AudiologyNOW!, April, 2010. San Diego, CA.

Carhart, R. L. (1949). Monitored live-voice as a test of auditory acuity. *Journal of the Acoustical Society of America, 17*, 339–349.

Carlson, M. L., Breen, J. T., Gifford, R. H., Driscoll, C. L. W., Neff, B. A., Beatty, C. W., . . . Olund, A. P. (2010). Cochlear implantation in the octogenarian and nonagenarian. *Otology & Neurotology, 31*, 1343–1349.

Carlson, M. L., Driscoll, C. L. W., Gifford, R. H., Service, G. J., Tombers, N. M., Hughes-Borst, B. J., . . . Beatty, C. W. (2011). Implications of minimizing trauma during conventional cochlear implantation. *Otology & Neurotology*, *32*, 962–968.

Centers for Medicare & Medicaid Services (CMS). (2005). National coverage determination (NCD) for cochlear implantation (50.3). Publication No. 100-3. Available at http://www.cms.gov/medicare-coverage-database/details/ncd-details.aspx?NCDId=245&ncdver=2&bc=BAABAAAAAAAA&

Chen, S. Y., Grisel, J. J., Lam, A., & Golub, J.S. (2017). Assessing cochlear implant outcomes in older adults using HERMES: A national web-based database. *Otology & Neurotology, 38*(10), e405–412.

Ching, T. Y., Incerti, P., & Hill, M. (2004). Binaural benefits for adults who use hearing aids and cochlear implants in the opposite ears. *Ear and Hearing*, *25*, 9–21.

Ching, T. Y., Psarros, C., Hill, M. Dillon, H., & Incerti, P. (2001). Should children who use cochlear implants wear hearing aids in the opposite ear? *Ear and Hearing*, *22*, 365–380.

Cochlear Corporation. (2003). Pre and post-operative evaluation manual for Nucleus® cochlear implant systems. FUZ139 ISS3, Oct 2003.

Coelho, D. H., Yeh, J., Kim, J. T., & Lalwani, A. K. (2009). Cochlear implantation is associated with minimal anesthetic risk in the elderly. *Laryngoscope, 119*, 355–358.

Cox, R. M., & Alexander, G. C. (1995). The abbreviated profile of hearing aid benefit. *Ear and Hearing, 16*, 176–186.

Dalbert, A., Huber, A., Baumann, N., Veraguth, D., Roosli, C., & Pfiffner, F. (2016). Hearing preservation after cochlear implantation may improve long-term word perception in the electric-only condition. *Otology & Neurotology, 37*(9), 1314–1319.

Davis, T. J., Zhang, D., Gifford, R. H., Dawant, B. M., Labadie, R. F., & Noble, J. H. (2015). Relationship between electrode-to-modiolus distance and current levels for adults with cochlear implants. *Otology & Neurotology,* 37, 31–37.

Deltenre, P., Mansbach, A. L., Bozet, C., Christiaens, F., Barthelemy, P., Paulissen, D., & Renglet, T. (1999). Auditory neuropathy with preserved cochlear microphonics and secondary loss of otoacoustic emissions. *Audiology*, *38*, 187–195.

Dillon, H., James, A., & Ginis, J. (1997). The Client Oriented Scale of Improvement (COSI) and its relationship to several other measures of benefit and

STUDENTS-HUB.com Uploaded By: tuka abuzneid

satisfaction provided by hearing aids. *Journal of the American Academy of Audiology, 8*, 27–43.

Dirks, D. D., Morgan, D. E., & Wilson, R. H. (1976). Experimental audiology. In C. A. Smith & J. A. Vernon (Eds.), *Handbook of auditory and vestibular research methods* (pp. 517–531). Springfield, IL: Charles C Thomas.

Etymotic Research. (2005). Bamford-Kowal-Bench Speech-in-Noise Test. Elk Grove Village, IL: Author.

Fabry, D., Firszt, J. B., Gifford, R. H., Holden, L. K., & Koch, D. (2009). Evaluating speech perception benefit in adult cochlear implant recipients. *Audiology Today, 21*, 37–42.

Fayad, J. N., & Linthicum, F. H. (2006). Multichannel cochlear implants: Relation of histopathology to performance. *Laryngoscope*, *116*, 1310–1320.

FDA NCT01066780. (2010). ClearVoice sound-processing strategy for AB HiRes 120 cochlear implant users. Food and Drug Administration clinical trial. Valencia, CA: Advanced Bionics.

Firszt, J. B., Holden, L. K., Reeder, R. M., Cowdrey, L., & King, S. (2012). Cochlear implantation in adults with asymmetric hearing loss. *Ear and Hearing*, *33*(4), 521–533.

Firszt, J. B., Holden, L. K., Skinner, M. W., Tobey, E. A., Peterson, A., Gaggl, W., . . . Wackym, P. A. (2004). Recognition of speech presented at soft to loud levels by adult cochlear implant recipients of three cochlear implant systems. *Ear and Hearing, 25*(4), 375–387.

Firszt, J. B., Reeder, R. M., Holden, L. K., & Dwyer, N. Y. (2018). Results in adult cochlear implant recipients with varied asymmetric hearing: A prospective longitudinal study of speech recognition, localization, and participant report. *Ear and Hearing*, *39*(5), 845–862.

Frewin, B., Chung, M., & Donnelly, N. (2013). Bilateral cochlear implantation in Friedreich's ataxia: A case study. *Cochlear Implants International, 14*(5), 287–290.

Friedland, D. R., Venick, H. S., & Niparko, J. K. (2003). Choice of ear for cochlear implantation: The effect of history and residual hearing on predicted postoperative performance. *Otology & Neurotology*, *24*, 582–589.

Furlong, W. J., Feeny, D. H., Torrance, G. W., & Barr, R. (2001). The Health Utilities Index (HUI) system for assessing health-related quality of life in clinical studies. *Annals of Medicine, 33*, 375–384.

Gantz, B. J., Tyler, R. S., Knutson, J. F., Woodworth, G., Abbas, P., McCabe, B. F., . . . Kuk, F. (1988). Evaluation of five different cochlear implant designs: Audiologic assessment and predictors of performance. *Laryngoscope*, *98*, 1100–1106.

Gantz, B. J., Woodworth, G. G., Knutson, J. F., Abbas, P. J., & Tyler, R. S. (1993). Multivariate predictors of audiological success with multichannel cochlear implants. *Annals of Otology, Rhinology, and Laryngology, 102*, 909–916.

Gassner, H. G., Shallop, J. K., & Driscoll, C. L. W. (2005). Long-term clinical course and temporal bone histology after cochlear implantation. *Cochlear Implants International*, *6*, 67–78.

Gatehouse, S. (1999). A self-report outcome measure for the evaluation of hearing aid fittings and services. *Health Bulletin*, 57, 424–436.

Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*, *43*(2), 85–99.

Gifford, R. H., Dorman, M. F., McKarns, S. A., & Spahr, (2007). Combined electric and contralateral acoustic hearing: Word and sentence recognition with bimodal hearing. *Journal of Speech and Language Hearing Research, 50*(4), 835–843.

Gifford, R. H., Dorman, M. F., Shallop, J. K., & Sydlowski, S. (2010). Evidence for the expansion of adult cochlear implant candidacy. *Ear and Hearing*, *31*(2), 186–194.

Gifford, R., Shallop, J. K., & Peterson A. M. (2008). Speech recognition materials and ceiling effects: Considerations for cochlear implant programs. *Audiology & Neurotology, 13*, 193–205.

Gopinath, B., Wang, J. J., Schneider, J., Burlutsky, G., Snowdon, J., McMahon, C. M., . . . Mitchell, P. (2009). Depressive symptoms in older adults with hearing impairments: The Blue Mountains Study. *Journal of American Geriatric Society, 57*(7), 1306–1308.

Goswamy, J., Bruce, I. A., Green, K. M., & O'Driscoll, M. P. (2012). Cochlear implantation in a patient with sensorineural deafness secondary to Charcot-Marie-Tooth disease. *Cochlear Implants International*, *13*(3), 184–187.

Gstoettner, W. K., van de Heyning, P., O'Connor, A. F., Morera, C., Sainz, M., Vermeire, K., . . . Adunka, O. F. (2008). Electric acoustic stimulation of the auditory system: Results of a multi-centre investigation. *Acta Oto-Laryngologica, 128*, 968–975.

Haplin, C., & Rauch, S. D. (2009). Hearing aids and cochlear damage: The case against fitting the pure tone audiogram. *Otolaryngology-Head and Neck Surgery*, *140*, 629–632.

Hinderink, J. B., Krabbe, P. F. M., & Broek, P. V. D. (2000). Development and application of a health-related quality-of-life instrument for adults with cochlear implants: The Nijmegen Cochlear Implant Questionnaire. *Otolaryngology–Head and Neck Surgery, 123*, 756–765.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Holder, J. T., Reynolds, S. M., Sunderhaus, L. W., & Gifford, R. H. (2018). Current profile of adults presenting for preoperative cochlear implant evaluation. *Trends in Hearing*, 22:2331216518755288.

Hood, L. J. (2015). Auditory neuropathy/dys-synchrony disorder: Diagnosis and management. *Otolaryngology Clinics of North America, 48*(6), 1027–1040.

Kamakura, T. & Nadol, J. B. Jr. (2016). Correlation between word recognition score and intracochlear new bone and fibrous tissue after cochlear implantation in the human. *Hearing Research*, 339, 132–141.

Kang, S., Chwodhury, T., Moon, I. J., Hong, S. H., Yang, H., Won, J. H., & Woo, J. (2015). Effects of electrode position on spatiotemporal auditory nerve fiber responses: A 3D computational model study. *Computational and Mathematical Methods in Medicine*. 2015, 934382. doi: 10.1155/2015/934382

Killion, M., Niquette, P., Revit, L., & Skinner, M. (2001). Quick SIN and BKB-SIN: Two new speech-in-noise tests permitting SNR-50 estimates in 1 to 2 min (A). *Journal of the Acoustical Society of America, 109*(5), 2502–2512.

Knutson, J. F., Johnson, A., & Murray, K. T. (2006). Social and emotional characteristics of adults seeking a cochlear implant and their spouses. *British Journal of Health Psychology, 11*(Pt. 2), 279–292.

Knutson, J. F., Murray, K. T., Husarek, S., Westerhouse, K., Woodworth, G. Gantz, B. J., & Tyler, R. S. (1998). Psychological change over 54 months of cochlear implant use. *Ear and Hearing*, *19*, 191–201.

Knutson, J. F., Schartz, H. A., Gantz, B. J., Tyler, R. S., Hinrichs, J. V., & Woodworth, G. (1991). Psychological change following 18 months of cochlear implant use. *Annals of Otology, Rhinology, and Laryngology*, *100*, 877–882.

Kochanek, K. D., Xu, J., Murphy, S. L., Minino, A. M., & Kung, H. C. (2011). Deaths: Preliminary data for 2009. *National Vital Statistics Reports, 59*(4), 1–51.

Kumar, A. U., & Jayaram, M. (2005). Auditory processing in individuals with auditory neuropathy. *Behavioral Brain Function*, *1*, 1–21.

Kumar, R. S., Mawman, D., Sankaran, D., Melling, C., O'Driscoll, M., Freeman, S. M., & Lloyd, S. K. (2016). Cochlear implantation in early deafened, late implanted adults: Do they benefit? *Cochlear Implants International, 17* (Suppl. 1), 22–25.

Leung, J., Wang, N. Y., Yeagle, J. D., Chinnici, J., Bowditch, S., Francis, H. W., & Niparko, J. K. (2005). Predictive models for cochlear implantation in elderly candidates. *Archives of Otolaryngology-Head & Neck Surgery*, *131*, 1049–1054.

Litvak, L. M., Spahr, A. J., & Emadi, G. (2007). Loudness growth observed under partially tripolar stimulation: Model and data from cochlear implant listeners. *Journal of the Acoustical Society of America*, *122*(2), 967–981.

Lu, C. B., & Schuknecht, H. F. (1994). Pathology of prelingual profound deafness. *American Journal of Otology, 15*, 74–85.

Marshall, A. H., Fanning, N., Symons, S., Shipp, D., Chen, J. M., & Nedzelski, J. M. (2005). Cochlear implantation in cochlear otosclerosis. *Laryngoscope, 115*, 1728–1733.

Martin, F. N., Champlin, C., & Chambers, J. A. (1998). Seventh survey of audiometric practices in the United States. *Journal of the American Academy of Audiology, 9*(2), 95–104.

McRackan, T. R., Hand, B. N., Velozo, C. A., & Dubno, J. R. (in press). Cochlear Implant Quality of Life (CIQOL): Development of a Profile Instrument (CIQOL-35 Profile) and a Global Measure (CIQOL-10 Global). *Journal of Speech, Language, and Hearing Research*.

Medwetsky, L., Sanderson, D., & Young, D. (1999). A national survey of audiology clinical practices, part 1. *Hearing Review, 6*(11), 24–32.

Morera, C., Manrique, M., Ramos, A., Garcia-Ibanez, L., Cavalle, L., Huarte, A., . . . Estrada, E. (2005). Advantages of binaural hearing provided through bimodal stimulation via a cochlear implant and a conventional hearing aid: A 6-month comparative study. *Acta Otolaryngologica, 125*, 596–606.

Mosnier, I., Bebear, J. P., Marx, M., Fraysse, B., Truy, E., Lina-Granade, G., . . ., Sterkers, O. (2015). Improvement of cognitive function after cochlear implantation in elderly patients. *Journal of the American Medical Association Otolaryngology Head and Neck Surgery*, *141*(5), 442–450.

MSTB. (2011). *Minimum Speech Test Battery For Adult Cochlear Implant Users*. Retrieved from http://auditorypotential.com/MSTBfiles/MSTBManual2011-06-20.pdf

Nachtegaal, J., Smit, J. H., Smits, C., Bezemer, P. D., van Beek, J. H., Festen, J. M., & Kramer, S. E. (2009). The association between hearing status and psychosocial health before the age of 70 years: Results from an Internet-based national survey on hearing. *Ear and Hearing, 30*(3), 302–312.

Nadol, J. B., & Hsu, W. (1991). Histopathologic correlation of spiral ganglion. *Annals of Otology, Rhinology, and Laryngology, 100*, 712–716.

Nadol, J. B., Shiao, J. Y., Burgess, B. J., Ketten, D. R., Eddington, D. K., Gantz, B. J., . . . Shallop, J. K. (2001). Histopathology of cochlear implants in humans. *Annals of Otology, Rhinology, and Laryngology*, *110*, 883–891.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Newman, C. W., Weinstein, B. E., Jacobson, G. P., & Hug, G. A. (1990). The Hearing Handicap Inventory for Adults: Psychometric adequacy and audiometric correlates. *Ear and Hearing, 11*, 430–433.

Nilsson, M. J., McCaw, V. M., & Soli, S. (1996). *Minimum speech test battery for adult cochlear implant users: User manual.* Los Angeles, CA: House Ear Institute.

Nilsson, M., Soli, S., & Sullivan, J. (1994). Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America, 95*, 1085–1099.

Noble, W., Jensen, N. S., Naylor, G., Bhullar, N., & Akeroyd, M. A. (2013). A short form of the speech, spatial, and qualities of hearing scale suitable for clinical use: SSQ12. *International Journal of Audiology*, *52*(6), 409–412.

Novak, M. A., Black, J. M., & Koch, D. B. (2007). Standard cochlear implantation of adults with residual low-frequency hearing: Implications for combined electro-acoustic stimulation. *Otology & Neurotology, 28*(5), 609–614.

O'Connell, B. P., Holder, J. T., Dwyer, R. T., Gifford, R. H., Noble, J. H., Bennett, M. L., . . . Labadie, R. F. (2017). Intra- and postoperative electrocochleography may be predictive of final electrode position and postoperative hearing preservation. *Frontiers in Neuroscience*, *11*, 291.

O'Connell, B. P., Hunter, J. B., Gifford, R. H., Rivas, A., Haynes, D. S., Noble, J. H., & Wanna, G. B. (2016). Electrode location and audiologic performance after cochlear implantation: A comparative study between nucleus CI422 and CI512 electrode arrays. *Otology & Neurotology, 37*(8), 1032–1035.

Olze, H., Grabel, S., Forster, U., Zirke, N., Huhnd, L. E., Haupt, H., & Mazurek, B. (2012). Elderly patients benefit from cochlear implantation regarding auditory rehabilitation, quality of life, tinnitus, and stress. *Laryngoscope*, *122*, 196–203.

Olze, H., Szczepek, A. J., Haupt, H., Förster, U., Zirke, N., Gräbel, S., & Mazurek, B. (2011). Cochlear implantation has a positive influence on quality of life, tinnitus, and psychological comorbidity. *Laryngoscope, 121*(10), 2220–2227.

Park, E., Shipp, D. B., Chen, J. M., Nedzelski, J. M., & Lin, V. Y. (2011). Postlingually deaf adults of all ages derive equal benefits from unilateral multichannel cochlear implant. *Journal of the American Academy of Audiology, 22*, 637–643.

Patrick, D. L., & Erickson, P. (1993). *Health status and health policy: Quality of life in health care evaluation and resource allocation.* New York, NY: Oxford University Press.

Pearsons, K. S., Bennett, R. L., & Fidell, S. (1977). *Speech levels in various noise environments* (Report No. EPA600/1-77-025). Washington, DC: U.S. Environmental Protection Agency.

Peterson, G. E., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech and Hearing Disorders, 27*, 62–72.

Philippon, D., Bergeron, F., Ferron, P., & Bussieres, R. (2010). Cochlear implantation in postmeningitic deafness. *Otology & Neurotology, 31*, 83–87.

Poissant, S. F., Beaudoin, F., Huang, J., Brodsky, J., & Lee, D. J. (2008). Impact of cochlear implantation on speech understanding, depression, and loneliness in the elderly. *Journal of Otolaryngology-Head and Neck Surgery, 37*(4), 488–494.

Potts, L. G., Skinner, M. W., Litovsky, R. A., Strube, M. J., & Kuk, F. (2009). Recognition and localization of speech by adult cochlear implant recipients wearing a digital hearing aid in the nonimplanted ear (bimodal hearing). *Journal of the American Academy of Audiology*, *20*, 353–373.

Prieve, B. A., Gorga, M. P., & Neely, S. T. (1991). Otoacoustic emissions in an adult with severe hearing loss. *Journal of Speech, Language and Hearing Research*, *34*, 379–385.

Quaranta, N., Bartoli, R., Lopriore, A., Fernandez-Vega, S., Giagnotti, F., & Quaranta, F. (2005). Cochlear implantation in otosclerosis. *Otology & Neurotology, 26*, 983–987.

Raffin, M. J. M., & Thornton, A. R. (1980). Confidence levels for differences between speech-discrimination scores: A research note. *Journal of Speech and Hearing Research, 23*, 5–18.

Robinson, K., Gatehouse, S., & Browning, G. G. (1996). Measuring patient benefit from otorhinolaryngological surgery and therapy. *Annals of Otology, Rhinology, and Laryngology, 105*, 415–422.

Roditi, R. E., Poissant, S. F., Bero, E. M., & Lee, D. J. (2009). A predictive model of cochlear implant performance in postlingually deafened adults. *Otology & Neurotology*, *30*, 449–454.

Roeser, R., & Clark, J. (2008). Live voice speech recognition audiometry: Stop the madness. *Audiology Today, 20*, 32–33.

Roland, J. T. Jr., Gantz, B. J., Waltzman, S. B., Parkinson, A. J., & Multicenter Clinical Trial Group. (2016). United States multicenter clinical trial of the cochlear nucleus hybrid implant system. *Laryngoscope*, *126*, 175–181.

Rubinstein, J. T., Parkinson, W. S., Tyler, R. S., & Gantz, J. (1999). Residual speech recognition and cochlear implant performance: Effects of implantation criteria. *American Journal of Otology, 20*(4), 445–452.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Sainz, M., Garcia-Valdecasas, J., & Ballesteros, J. M. (2009). Complications and pitfalls of cochlear implantation in otosclerosis: A 6-year follow-up cohort study. *Otology & Neurotology*, *30*, 1044–1048.

Sainz, M., García-Valdecasas, J., Garófano M., & Ballesteros, J. M. (2007). Otosclerosis: Mid-term results of cochlear implantation. *Audiology & Neurotology, 12*, 401–406.

Seyyedi, M., Viana, L. M., & Nadol, J. B. Jr. (2014). Within-subject comparison of word recognition and spiral ganglion cell count in bilateral cochlearimplant recipients. *Otology & Neurotology, 35*, 1446–1450.

Shivashankar, N., Satishchandra, P., Shashikala, H. R., & Gore, M. (2003). Primary auditory neuropathy: An enigma. *Acta Neurologica Scandinavica, 108*, 130–135.

Skinner, M. W., Holden, L. K., Holden, T. A., Demorest, E., & Fourakis, M. S. (1997). Speech recognition at simulated soft, conversational, and raised-to-loud vocal efforts by adults with cochlear implants. *Journal of the Acoustical Society of America, 101*(6), 3766–3782.

Sladen, D. P., Gifford, R. H., Haynes, D., Kelsall, D., Benson, A., Lewis, K., . . . Driscoll, C. L. (2017). Evaluation of a revised indication for determining adult cochlear implant candidacy. *Laryngoscope*, *127*(10), 2368–2374.

Spahr, A. J., Dorman, M. F., Litvak, L. L., Van Wie, S., Gifford, R. H., Loizou, P. C., . . . Cook, S. (2012). Development and validation of the AzBio sentence lists. *Ear and Hearing*, *33*, 112–117.

Starr, A., Picton, T. W., Sininger, Y., Hood, L. J., & Berlin, C. I. (1996). Auditory neuropathy. *Brain, 119*, 741–753.

Stuart, A., & Mills, K. N. (2009). Late-onset unilateral auditory neuropathy/dysynchrony: A case study. *Journal of the American Academy of Audiology, 20*, 172–179.

Thigpen, M. C., Whitney, C. G., Messonnier, N. E., Zell, E. R., Lynfield, R., Hadler, J. L., . . . Schuchat, A., Emerging Infections Programs Network. (2011). Bacterial meningitis in the United States, 1998– 2007. *New England Journal of Medicine, 26, 364*(21), 2016–2025.

Tucker, M. A. (2001). *A time study of audiological practice patterns and the impact of reimbursement changes from third party payers*. Unpublished thesis, University of South Florida, Tampa, FL.

Valente, M., Abrams, H., Benson, D., Chisolm, T., Citron, D., Hampton, D., . . . Sweetow, R. (2006). Guidelines for the audiologic management of adult hearing impairment. *Audiology Today, 18*(5), 1–44.

Ventry, I. M., & Weinstein, B. E. (1982). The Hearing Handicap Inventory for the Elderly: A new tool. *Ear and Hearing*, *3*, 128–134.

Wackym, P. A., Runge-Samuelson, C. L., Firszt, J. B., Alkaf, F. M., & Burg, L. S. (2007). More challenging speech perception tasks demonstrate binaural benefit in bilateral cochlear implant users. *Ear and Hearing, 28*, 80S–85S.

Waltzman, S. B., Fisher, S. G., Niparko, J. K., & Cohen, L. (1995). Predictors of postoperative performance with cochlear implants. *Annals of Otology, Rhinology, and Laryngology Supplement*, *165*, 15–18.

Wanna, G. B., Noble, J. H., Carlson, M. L., Gifford, R. H., Dietrich, M. S., Haynes, D. S., . . . Labadie, R. F. (2014). Impact of electrode design and surgical approach on scalar location and cochlear implant outcomes. *Laryngoscope, 124* (Suppl. 6), S1–7.

Wanna, G. B., O'Connell, B. P., Francis, D. O., Gifford, R. H., Hunter, J. B., Holder, J. T., . . . Haynes, D. S. (2018). Predictive factors for short- and long-term hearing preservation in cochlear implantation with conventional-length electrodes. *Laryngoscope*, 128, 482–489.

Witte, R. J., Lane, J. I., Driscoll, C. L., Lundy, L. B., Bernstein, M. A., Kotsenas, A. L., & Kocharian, A. (2003). Pediatric and adult cochlear implantation. *Radiographics, 23*(5), 1185–1200.

Woodson, E. A., Reiss, L. A. J., Turner, C. W., Gfeller, K., & Gantz, B. J. (2010). The Hybrid cochlear implant: a review. *Advances in Otorhinolaryngology*, 67, 125–134.

World Health Organization (WHO). (2011). Global health and aging. https://www.who.int/ageing/publications/global_health.pdf?ua=1

Zwolan, T. A., Henion, K., Segel, P., & Runge, C. (2014). The role of age on cochlear implant performance, use, and health utility: a multicenter clinical trial. *Otology & Neurotology, 35*, 1560–1568.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

3

Pediatric Cochlear Implant Candidate Selection

René H. Gifford

INTRODUCTION

As mentioned in Chapter 2, determining cochlear implant candidacy can be a complex process. This is particularly true when assessing candidacy for infants and children. Pediatric cochlear implantation was first approved by the Food and Drug Administration (FDA) in June 1990 and was last updated in 2000 when the minimum age was lowered to 12 months. Pediatric-labeled indications vary with age, etiology, as well as across the different manufacturers. Furthermore, there are a number of auditory-related milestones for which, even if they are not met, implant candidacy may be determined regardless of whether the child meets the typical candidate profile.

There are many aspects requiring careful consideration in the process of pediatric cochlear implant candidate selection, including medical, radiologic, and psychological issues. This chapter discusses pediatric cochlear implant candidate selection, including aspects to be considered from the perspective of the audiologist, speech/language pathologist, social worker and/or psychologist, as well as the medical/surgical team. The chapter also describes the elements of cochlear implant candidate selection for children with hearing loss as it stands today, as well as discusses those elements that, as a field, we may want to consider in the evaluation process.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

AUDIOLOGIC EVALUATION

Assessment of Hearing Status

As with adult candidacy evaluations, virtually all pediatric cochlear implant evaluations begin in the audiology clinic. The cochlear implant evaluation is ordinarily preceded by numerous appointments in the diagnostic audiology clinic for behavioral hearing testing, as well as objective estimates of auditory function, including otoacoustic emissions and auditory brainstem response. The pediatric

cochlear implant evaluation process does not involve the initial diagnosis of a severe-to-profound hearing loss, as children and their families present to the evaluation with a confirmed diagnosis and hearing aid experience; thus, the family arrives at the appointment with knowledge and at least partial acceptance of the diagnosis. This generally helps facilitate discussion about cochlear implants without the presence of a raw emotional component that accompanies new diagnoses. For those audiologists engaging in all aspects of pediatric audiologic care, a patient and family will be followed from initial diagnosis to hearing aid fittings, follow-up, assessment of auditory progress, through determination of cochlear implant candidacy. Given the demand for highly skilled pediatric cochlear implant audiologists, it is generally not the case that a single provider is involved in all previous diagnostic and amplification-related appointments—though such continuity of care would certainly be valuable to a family facing a number of new experiences following diagnosis of hearing loss.

Despite the fact that most families present to the first implant evaluation with prior audiograms and objective estimates of auditory function, it is recommended that comprehensive audiometric testing be completed. This is an obvious opportunity to gain additional ear-specific pure-tone and speech awareness information, particularly for frequencies that prior audiograms may have been lacking. It is also appropriate to complete tympanograms and, at a minimum, ipsilateral middle ear muscle reflexes. Given that multiple assessments of behavioral hearing status and hearing aid fitting are recommended prior to finalizing candidate selection, it is generally the case that a child is not seen by the cochlear implant team for assessment at least until 6 months of age, which is generally the age at which reliable behavioral assessment of hearing can be completed; thus, the earliest implant evaluation/workup appointments involve visual reinforcement, audiometry and/or behavioral observation audiometry. This task becomes more complicated for the assessment of children with concomitant diagnoses that may delay sitting up, independent head and neck control, and more global developmental and/or cognitive abilities.

Otoacoustic emissions (OAEs) provide valuable information for the cochlear implant evaluation. Although most newborn hearing screening programs in well-baby nurseries utilize OAEs as a first-pass screening tool (e.g., Gravel et al., 2005; JCIH, 2007; White et al., 2005), not all children will have had this completed. Virtually every cochlear implant audiologist has at least one story about a patient presenting for an evaluation who is diagnosed with auditory neuropathy spectrum disorder (ANSD) *after* the cochlear implant evaluation appointment. Although ANSD does not preclude a patient from cochlear implantation (e.g., Alzhrani, Yousef, Almuhawas & Almutawa, 2019; Breneman, Gifford & DeJong, 2012; Shallop, Peterson, Facer, Fabry, & Driscoll, 2001; Peterson et al., 2003; Rance & Barker, 2008; Teagle et al., 2010), it is important to have an accurate diagnosis in place, as well as to explore all possible habilitative options, such as effectiveness of acoustic amplification, prior to pursuing surgical intervention.

Cochlear Implant Criteria: Audiometric Thresholds

Audiometric-based criteria for cochlear implantation differ across implant manufacturers. For pediatric candidacy, there is an additional element of age-specific audiometric criteria. For children age 12 to 24 months, the current criteria specify bilateral *profound* sensorineural hearing loss (see Cochlear package insert, Advanced Bionics package insert, MED-EL package insert). This is not to imply that children with less severe hearing losses would not benefit from cochlear implantation. Rather, the historical concern has been that obtaining behavioral thresholds for the youngest children was more difficult than for older children; hence, the criteria were most stringent for the youngest candidates. This concern may not be as valid today given the audiologic checks and balances that are at our disposal for both behavioral assessments of hearing and objective/physiologic estimates of auditory function. In fact, this is also an argument for lowering the FDA-approved age for cochlear implantation from 12 months to slightly younger—perhaps in the 6- to 9-month range (e.g., Cosetti & Roland, 2010; Kim, Jeong, Lee, & Kim, 2010). Research has demonstrated significant benefit for children implanted in the 1st year of life, even as com-

STUDENTS-HUB.com Uploaded By: tuka abuzneid

pared to children implanted in the 2nd year of life, on measures of word and language acquisition (Bergeson, Houston, & Miyamoto, 2010; Houston & Miyamoto, 2010; Niparko et al., 2010; Moog & Geers, 2010; Houston, Stewart, Moberly, Hollich & Miyamoto, 2012, Houston et al., 2012 Tobey et al., 2013; Dettman et al., 2016; Miyamoto, Colson, Henning & Pisoni, 2017), speech perception (Tajudeen, Waltzman, Jethanamest & Svirsky, 2010; Holman et al., 2013), speech intelligibility (Habib, Waltzman, Tajudeen, & Svirsky., 2010), and vocabulary development (Hayes, Geers, Treiman, & Moog, 2009; Houston & Miyamoto, 2010; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005).

There are a number of developmental changes occurring within the first year of life that may be missed for the infant with severe-to-profound hearing loss. This is true even for those infants with appropriately fitted hearing aids, given that the audibility may be insufficient to allow for consistent auditory access to spoken language. Word segmentation, which is the process of dividing connected discourse into meaningful units, such as individual words, has been shown to develop rapidly between 7.5 and 10.5 months (Jusczyk, 2002). By 8 months of age, babies have the capacity for long-term storage of new words, which is an important prerequisite for auditory-based language learning (Jusczyk & Hohne, 1997; Houston & Jusczyk, 2003). Thus the infant with severe-to-profound sensorineural hearing loss, for whom aided audibility is limited, is missing out on the development of these critical auditory-based, language-learning opportunities occurring in the 1st year of life (Levine, Strother-Garcia, Golinkoff, & Hirsh-Pasek, 2016). The reality is that if a child is not making auditory progress with full-time use of appropriately fitted hearing aids and compliance with the recommended intervention and therapy schedule, that child meets cochlear implant "candidacy" based on the professional clinical judgment of the cochlear implant team (see Chapter 1).

For children over 2 years of age, the audiometric criteria for implantation with a Cochlear device are more lenient, including bilateral severe-to-profound sensorineural hearing loss, allowing for slightly more residual acoustic hearing. Both Advanced Bionics and MED-EL, however, continue to list bilateral profound sensorineural hearing loss in the labeled indications for children over 2 years of age. Nevertheless, if a child has moderate-to-profound sensorineural hearing loss and is not making auditory progress with appropriately fitted hearing aids and intervention, the cochlear implant team has the professional clinical judgment to determine candidacy (see Chapter 1). There are a number of studies that have demonstrated significant improvements in speech recognition and language for children with bilateral sensorineural hearing losses outside the range of labeled candidacy (Carlson et al., 2014; Leigh, Dettman, & Dowell, 2016; Schaefer et al., 2019).

Speech-Perception Metrics

Much of the preoperative assessment in this section can also be found in the Pediatric Minimum Speech Test Battery [PMSTB (Uhler, Warner-Czyz, & Gifford, 2017)]. The PMSTB was published in 2017 following five years of literature review and critical discussion within an independent working group of nearly 60 pediatric clinicians (audiologists and speech/language pathologists), hearing scientists, and industry representatives. The PMSTB tutorial and manual is frequently referenced throughout this book and can be accessed from the *Journal of the American Academy of Audiology*.

SPEECH-RECOGNITION TESTING

Recorded Materials

A central component of pediatric cochlear implant evaluations for older children involves the behavioral assessment of speech recognition abilities. Many children with hearing loss rely heavily on visual cues such as lip reading and more global nonverbal communication; thus, in order to gain an understanding of an individual's auditory only speech recognition abilities, speech stimuli are presented without visual cues.

As with adult candidacy assessment, the most important aspect surrounding the administration of speech recognition testing for older children involves the use of recorded speech

STUDENTSHUB.com Uploaded By: tuka abuzneid

materials. As shown in Chapter 2, Figure 2–1, it is clear that the variability associated with monitored live voice (MLV) presentation does not lend itself well to the assessment of pediatric cochlear implant candidacy. Indeed, Uhler and colleagues (2016) demonstrated that there was a 13-percentage point difference (range: 0- to 28-percentage points) between MLV and recorded stimulus presentation for a group of 29 pediatric cochlear implant recipients aged 4 to 17 years. It is important to note, however, that there are some pediatric speech metrics that are not currently available in recorded format; however, none of the measures that were designed for MLV presentation are indicated for use in the determination of pediatric cochlear implant candidacy and thus do not influence whether or not a child qualifies for implant candidacy. At the time of chapter preparation, Advanced Bionics' package insert of FDA-labeled indications specify administration of the Multisyllabic Lexical Neighborhood Test (MLNT) (Kirk, Pisoni, & Osberger, 1995) administered using MLV at 70 dB SPL. Given that the MLNT and its monosyllabic equivalent, the Lexical Neighborhood Test (LNT) (Kirk, Pisoni, & Osberger, 1995) are both available in recorded format, MLV presentation would be contraindicated by the PMSTB and best practices for pediatric audiology.

Despite the variability and associated problems with assessing speech recognition via MLV, depending on a child's age and/or global developmental status, MLV may be required to elicit reliable responses. Live voice from a familiar, trusted audiologist is a simpler speech recognition task from that of using a recorded speech stimulus. The recorded voice is unfamiliar and often lacks the affect that is found in the speaking style of an individual trained to work with children. It is also for this reason that overly accentuated suprasegmental features of a pediatric audiologist's spoken words along, with a slower rate of speech, may yield higher levels of speech recognition than that experienced in everyday communicative settings. Furthermore, the test/retest reliability of speech recognition performance obtained via MLV is poorer than that for recorded stimuli (Carhart, 1946; Kruel, Bell, & Nixon, 1969; Uhler et al., 2016), and thus it is not appropriate for use in cochlear implant candidate selection. Should a child respond only to a familiar voice via MLV and continue to exhibit poor recognition, it is reasonable to determine implant candidacy because speech recognition with standardized, recorded stimuli is either equivalent to or poorer than that obtained via MLV (Roeser & Clark, 2008; Uhler et al., 2016). (See Chapter 2 for detailed information regarding calibration of recorded stimuli for presentation in the sound field.)

Presentation Level

An important aspect of speech recognition testing for cochlear implant evaluations involves the presentation level of the recorded speech stimuli. As discussed in Chapter 2, 60 dB SPL is the recommended presentation level as it is representative of average conversational level speech (Olsen, 1998; Pearsons et al., 1977). Best practices recommendations for adult implant assessments have included the use of recorded speech materials presented at 60 dBA (see Chapter 2) for assessment of speech recognition for pre- as well as post-implant testing; thus, it also follows that the *highest* presentation level for pediatric candidacy assessment would be 60 dBA. Indeed, the PMSTB specifies speech recognition testing at multiple presentation levels (i.e., conversational speech in quiet [60 dBA], conversational speech in noise [65 dBA], soft speech level [50 dBA]) using a hierarchical array of speech stimuli (i.e., phonemes, words, and sentences). The addition of a lower presentation level for pediatric assessment is based on acoustic analyses of average speech levels, demonstrating that, on average, casual speech levels for children and women range from 50 to 56 dBA (Table 3–1) (Olsen, 1998; Pearson et al., 1977). Furthermore, we recognize that children may not always be situated at an optimum distance from a talker resulting in a lower ear-level SPL. Thus, it is recommended that pediatric speech recognition assessments include average and lower average presentation levels.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Multiple Estimates of Speech Recognition

Unlike assessment for adult implant candidates, older children fitted with hearing aids may be seen multiple times over several months—this is par-

Table 3–1. Mean speech levels (in dBA) and unweighted sound pressure levels for casual, normal, raised, loud, and shouted speech by men, women, and children in an anechoic chamber*

	Casual	Normal	Raised	Loud	Shouted
Women	50 [54] (4)	55 [58] (4)	63 [65] (4)	71 [72] (6)	82 [82] (7)
Men	52 [56] (4)	58 [61] (4)	65 [68] (5)	76 [77] (6)	89 [89] (7)
Children	53 [56] (5)	58 [61] (5)	65 [67] (7)	74 [75] (9)	82 [82] (9)

*Unweighted sound pressure levels are given in brackets and standard deviations are given in parentheses. All values are rounded to the nearest decibel.

Source: From Olsen (1998) and Pearsons et al. (1977).

ticularly true for the borderline candidate. Multiple visits are required to determine whether or not a child is making progress with appropriately fitted hearing aids and intervention. Although there are not currently any recommended guidelines for the frequency of candidacy-based assessment and the time period over which these assessments should take place, FDA-labeled indications state that a hearing aid trial of at least 6 months should be completed prior to determining candidacy; thus, it is the responsibility of each implant team to determine their own protocol dictating the number of audiologic assessments that should take place over that 6-month period. The obvious exception lies in cases of meningitis, for which cochlear ossification can limit electrode insertion and outcomes; FDA-labeled criteria currently specify that a shorter hearing aid trial is acceptable and appropriate in such cases. Shorter hearing aid trials are also standard practice in cases of older children who have experienced progressive hearing loss, sudden onset hearing loss, or those with late identification. The primary concern regarding a compressed hearing aid trial is that the least invasive treatment option be fully considered prior to determination of implant candidacy.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Speech Discrimination and Recognition Test Materials: Up to 3 Years of Age

Current labeled indications for pediatric cochlear implantation do not make reference to closed-set metrics of speech perception as listed here, though this does not mean that these metrics are not valuable instruments in a clinician's toolbox for assessing speech recognition performance and progress prior to determining implant candidacy. Such metrics are indeed recommended for our youngest patients if for no other reason than to provide a baseline measurement against which preoperative progress with hearing aids and/or postoperative progress can be gauged.

Auditory-skills development for the younger child is usually gauged via auditory questionnaire data, parental report, and speech/language assessment. This is particularly true for the youngest children with severe-to-profound sensorineural hearing loss for whom we expect little progress on auditory skills and auditory/oral language development. The obvious exception to this rule is in the case of younger children with acquired hearing loss and/or progressive hearing loss.

There are a variety of standardized measures of speech discrimination or recognition that are appropriate for the younger child. In this chapter we will highlight those measures that are currently recommended by the PMSTB. Audiologists generally begin with *closed-set tests* for which a limited set of possible choices are available and a verbal response is not required.

Visual Reinforcement Infant Speech Discrimination (VRISD)

VRISD is based on the principle of a conditioned head turn as used in visual reinforcement audiometry (VRA), making it ideal for use with infants between 6 and 24 months of age. Unlike conventional VRA which requires a child to detect a

sound, VRISD allows us to identify situations in which a child detects a change in sound. VRISD operates via operant conditioning by reinforcing a head turn to a correct response (or a hit) using animated video or mechanical toy reinforcement. Infant speech discrimination can be assessed using several sound contrasts within a test session or across a number of test sessions. The most common speech stimuli utilized in VRISD protocols are vowel contrasts such as /a/ versus /i/ and /a/ versus /u/, which are differentiated on the basis of spectral cues. Vowel contrasts have been shown to be easier for younger infants and emerge earlier as compared to contrasts based on voice onset time (e.g., /ta/ vs. /da/) or place of articulation (e.g., /ba/ vs. /da/) (Eilers, Wilson, & Moore, 1977; Eilers, Morse, Gavin, & Oller, 1981; Boothroyd, 1984; van Wieringen & Wouters, 1999; Uhler, Yoshinaga-Itano, Gabbard, Rothpletz & Jenkins, 2011; Warner-Czyz & Sweeney, 2013). VRISD is typically administered until a child reaches 75% discrimination proficiency of validated and normed contrasts including /ba/ versus /da/ and /a/ versus /i/ (Uhler, Baca, Dudass & Fredrickson, 2015; Uhler et al., 2018).

Though there are no current recommendations regarding use of VRISD for determining pediatric implant candidacy, VRISD can be a powerful tool in an audiologist's repertoire as it allows us to identify whether an infant is making expected developmental gains in speech sound discrimination following acoustic amplification and intervention. VRISD has historically held a larger presence in research and has yet to gain widespread clinical use; however, with the inclusion of VRISD in the PMSTB protocol (Uhler, Warner-Czyz, & Gifford, 2017), this tool has gained greater attention and is working its way into more clinical protocols.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Closed Set Speech Recognition Tests

Closed-set tests include a limited set of possible choices for which a verbal response is not required. The ESP standard version for word recognition is a closed-set task of word recognition recommended for children aged 2 to 5 years, depending on the child's developmental auditory and language skills. The ESP standard version includes two sub-tests including spondee and monosyllabic word identification, respectively. Both the spondee and monosyllabic subtests require that the child select 1 out of 12 color pictures corresponding to the spoken word. The 12 words are presented twice for a given run corresponding to a total possible of 24 correct words.

The Pediatric Speech Intelligibility (PSI; S. Jerger & J. Jerger, 1984) word test can be used for children as young as 3 years up to approximately 7 years of age. The PSI word task is administered by use of a carrier phrase "show me" followed by the target word. Children are instructed that they will hear a man say "show me" and that the child should point to the picture that matches the word. Older children can simply repeat the target word. The PSI word test includes 20 words presented on five picture cards each containing four pictures.

The PSI sentence test is the next and last option in the PMSTB protocol for closed-set tasks. The PSI sentence test includes 10 sentences arranged in two closed-set items each with five sentences. As with the PSI words, the PSI sentences were developed from actual responses of children aged 3 to 6 years with normal hearing in response to picture prompts (Jerger et al., 1980). The PSI sentence test was recorded with two formats which differ in carrier phrase prior to sentence delivery. Format I uses the carrier phrase "show me" prior to sentence delivery whereas Format II omits the use of the carrier phrase. The use of Format I is better suited to younger children (<5 years) whereas Format II is more appropriate for older, school-aged children (5+ years).

It is important to note that although these closed-set tasks can be useful for assessment of speech recognition skills in young children, these measures are not currently listed in the labeled indications for pediatric cochlear implantation. However, should a closed-set task be consistent with the developmental level for a particular cochlear implant candidate, these tasks could be used as part of the preoperative evaluation to describe a child's overall auditory profile.

Speech-Recognition Test Materials in Older Children

Current implant candidacy criteria for older children are based on either monosyllabic or multi-

syllabic word recognition depending on which is developmentally appropriate for the child being evaluated. The tests that are listed by the cochlear implant manufacturers in their FDA labeling are as follows (presented in order of developmentally appropriate progression): Multisyllabic Lexical Neighborhood Test (MLNT) (Kirk et al., 1995), Lexical Neighborhood Test (LNT) (Kirk et al., 1995), Phonetically Balanced Kindergarten (PBK) word recognition test (Haskins, 1949), and HINT sentences for children (HINT-C) (Gelnett, Sumida, Nilsson, & Soli, 1995). Please note that of the measures listed in the FDA labeling, only the MLNT and LNT are recommended by the PMSTB. For older children, the PMSTB recommendations include a progression of words (MLNT, LNT, CNC) followed by sentences in quiet (BKB, Pediatric AzBio), and finally sentences in noise (BKB-SIN, Pediatric AzBio).

Word Recognition: >3 Years

The MLNT and LNT (Kirk et al., 1995) are referenced in the labeled indications for pediatric cochlear implantation for candidate selection of children with limited vocabularies, as well as in the PMSTB (Uhler et al., 2017). Both MLNT and LNT were developed with the Neighborhood Activation Model (Luce & Pisoni, 1998), which considers both word frequency and lexical density in spoken word recognition. Word frequency simply refers to how often a particular word occurs in spoken language for a given age range. Lexical density refers to the number of phonemically similar words to the target word (Greenberg & Jenkins, 1964; Landauer & Streeter, 1973). The term "lexical neighbor" refers to a word differing by one phoneme such as pit, hot, hat, his, hid, and sit being neighbors of the target word "hit." Target words that have a large number of lexical neighbors are said to arise from "dense" lexical neighborhoods; in contrast, words with few lexical neighbors are said to arise from "sparse" lexical neighborhoods. The "easy" MLNT and LNT lists include high-frequency words from sparse lexical neighborhoods. The "hard" MLNT and LNT lists include lower frequency words from dense lexical neighborhoods (Luce, 1986; Luce, Pisoni, & Goldinger, 1990; Luce & Pisoni, 1998).

The MLNT lists include 12 words each that can scored both in terms of whole word accuracy as well as phoneme accuracy. The MLNT includes 2 lexically easy and 2 lexically hard lists. The LNT list includes 25 words each that can also be scored in terms of whole word and phoneme accuracy. Similar to the MLNT, the LNT includes 2 lexically easy and 2 lexically hard lists. Both the MLNT and LNT recordings include single speaker tracks as well as multi-speaker tracks.

For older children who are capable of completing more complex word recognition tasks—typically 5 years or older—the next recommended measure is monosyllabic word recognition with the CNC word lists (Peterson & Lehiste, 1962). The CNC test includes ten 50-word lists of equivalent intelligibility. The CNC recordings contain a single male talker using the carrier phrase "ready" prior to the target word. This carrier phrase serves as an effective orienting tool for a child who may be easily distracted. As with other word tasks, CNC words are generally scored both for whole word and phoneme accuracy.

Open-Set Sentence Recognition: 3+ Years

The BKB sentence corpus recommended for use in children uses the split sentence tracks from the BKB-SIN (Etymotic, 2005) which includes 16 sentence lists, each with 50 to 62 key words. The BKB sentences are spoken by a single male speaker using the carrier word "ready" prior to each sentence. The BKB sentences presented in quiet can be scored as overall percent key words repeated correctly.

The pediatric AzBio sentences (Spahr et al., 2014), also commonly referred to as the "BabyBio" test, includes 16 lists of equivalent difficulty, each with 20 unique sentences. Sentence length ranges from 3 to 12 words and are scored as overall percent words repeated correctly. Unlike the majority of the other recorded stimuli, BabyBio sentences are spoken by a single female talker.

Speech Recognition in Noise

Assessing speech recognition in noise is a reasonable endeavor as children are rarely in quiet

STUDENTS-HUB.com Uploaded By: tuka abuzneid

listening environments. Current FDA indications, however, do not suggest the use of speech-in-noise testing for determining either adult or pediatric implant candidacy. Educational acoustic research has shown that occupied classroom noise can range from 48 to over 70 dBA, with the mean level approximately 65 dBA for an early elementary classroom (e.g., Sanders, 1965; L. Nober & E. Nober, 1975; Bess, Sinclair, & Riggs, 1984; Finitzo-Hieber, 1988; Crukley, Scollie & Parsa, 2011). Considering a child's listening environment both inside and outside the classroom, research has shown that Leq 24-hr measurement averages 87.3 dBA for all students and 95.5 dBA for fifth graders (Clark & Govett, 1995). Given that a child's everyday listening environment is much noisier than even that encountered by the typical adult, it follows that in the process of determining implant candidacy speech recognition in noise should be standard practice. The PMSTB recommends the use of both the Pediatric AzBio (BabyBio) sentences in noise as well as the BKB-SIN. The BabyBio sentences are recommended for presentation at 65 dB SPL in a +5 dB SNR to increase the ecological validity of the assessment (Pearsons, Bennett, & Fidell, 1977; Smeds, Wolters, & Rung, 2015). An additional speech-in-noise measure is the BKB-SIN.

Thinking Beyond the "Criteria Checklist" for Pediatric Candidate Selection

Older children assessed with word and sentence recognition testing are required to exhibit considerably lower performance than even that listed for adult FDA implant labeling. Word-recognition candidacy criteria for the older child ranges from 12% to 30% correct in the best-aided condition across the three manufacturers. Advanced Bionics further lists performance up to 30% correct for HINT-C sentences, when developmentally appropriate for children over 4 years. This same manufacturer, however, lists up to 50% HINT sentence recognition performance for adult candidates. One must question the reasoning behind listing disproportionally restrictive criteria for pediatric implant criteria given that children are in the process of acquiring auditory-based speech and language. It is for this reason that the need for the expansion of pediatric cochlear implant criteria has been and remains to be a hot topic. An ever increasing body of literature has emerged supporting a relatively narrow critical period for cochlear implantation for the development of listening and spoken language (Hayes et al., 2009; Moog & Geers, 2010; Bergeson et al., 2010; Niparko et al., 2010; Habib et al., 2010; Houston & Miyamoto, 2010) as well as auditory pathway maturation (Ponton et al., 2000; Sharma, Dorman, Spahr & Todd, 2002; Eggermont & Ponton, 2003; Gordon, Papsin & Harrison, 2005, 2006; Kral, Tillein, Heid, Klinke, & Hartmann, 2006; Sharma & Dorman, 2006; Gilley, Sharma, & Dorman, 2008; Sharma, Nash & Dorman, 2009). It seems reasonable that the combined fields of otology, audiology and speech/language pathology are questioning the reasoning behind labeling the most stringent candidacy criteria for the youngest of auditory language learners and that criterion level performance should more closely approximate or even exceed that which is outlined for adult implant candidates.

EVALUATION OF AUDITORY SKILLS AND PROGRESS IN INFANTS AND CHILDREN 3 YEARS OF AGE OR LESS

Determining a child's auditory skills and progress with hearing aids prior to determining implant candidacy is not as easy as studying the audiogram. It is well known that similar audiograms do not necessarily yield similar levels of benefit from amplification across a range of hearing losses and configurations. Given that speech-recognition performance cannot be completed for infants and many toddlers, it is critical that the candidacy evaluation process include assessment of auditory skills, development, and progress with hearing aids. From the perspective of the audiologist, these skills will most likely be assessed via parental history and administration of validated questionnaires that are designed to gauge a child's auditory-based responsiveness to sounds in their environment.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

The PSMTB recommends administration of the LittlEARS auditory questionnaire (Weichbold, Tsiakpini, Coninx, & D'Haese, 2005; Coninx et al., 2009) and the Auditory Skills Checklist (ASC; Meinzen-Derr, Wiley, Creighton, & Choo, 2007) for assessing auditory skills in children at both pre- and post-implant appointments. The LittlEARS is composed of 35 yes/no questions designed to gauge a child's auditory-based responses to different sounds and environments. The questions are organized hierarchically. with a progression of difficulty so that the parent can stop answering questions following six consecutive "no" answers. It is designed for use in children up to 24 months of age for normal hearing or 24 months following implantation, though a child with normal development would be expected to reach ceiling levels prior to that test point. Administration of LittlEARS takes very little time, and because it does not require parental interview, it does not need to take up time during the actual appointment. The LittlEARS is validated in a number of languages including English, Spanish, German, Hebrew, and Arabic (Coninx et al., 2009; Spitzer & Zavala, 2011; Geal-Dor et al., 2011).

The ASC (Meinzen-Derr et al., 2007) was developed in response to the increasing number of children being implanted under 12 months of age. The ASC is a 35-item questionnaire that assesses detection, discrimination, identification, and comprehension. The ASC is designed to be administered in a parental-interview style as well as via clinician observation for which the parent/administrator assigns a rating ranging from 0 to 2 as follows: 0, child does not have the skill; 1, child has demonstrated emerging skill development; and 2, child consistently demonstrates the skill. As compared to the LittlEARS, the ASC can be used over a longer period of time (for children implanted up to 3 years of age) and it provides a detailed multidimensional assessment over smaller increments of auditory-skill development.

Though not recommended by the PMSTB, one of the most common questionnaires used for children from birth to 3 years is the Infant–Toddler version of the Meaningful Auditory Integration Scale (IT-MAIS) (Zimmerman-Phillips, Robbins, & Osberger, 2000). All three cochlear implant companies make reference to the MAIS (Robbins, Renshaw, & Berry, 1991) and/or IT-MAIS for use in determining auditory progress with amplification. For the youngest of children, the 10-item IT-MAIS is frequently used due to the widespread familiarity of the metric as well as the ease and time required of administration (<10 min). As shown in Figure 3–1, the IT-MAIS is designed to be administered in a structured, parental-interview format and thus requires that the clinician interpret open-ended responses and assign numerical scores ranging from 0 (never) to 4 (always).

In addition to the PMSTB recommendations and the IT-MAIS/MAIS as mentioned in the labeled indications, there are a number of other questionnaires that clinicians may find useful in the infant to toddler group. The Functioning After Pediatric Cochlear Implantation (FAPCI) questionnaire (Lin et al., 2007) is a 23-item FAPCI is considered appropriate for the 2- to 5-year-old range and does not require parental interview for administration. Using the FAPCI during the candidacy process provides clinicians and families with a baseline against which future growth in auditory skills can be gauged.

The Functional Auditory Performance Indicators (FAPI) (Stredler-Brown & DeConde Johnson, 2003) assesses seven categories of auditory development, including sound awareness, meaningful sounds, auditory feedback, sound localization, discrimination, short-term auditory memory,

STUDENTS-HUB.com Uploaded By: tuka abuzneid



FIGURE 3–1. Shown here is a clinician administering an auditory questionnaire using a parental interview style.

and linguistic auditory processing. The clinician assigns a score for each category as emerging (0% to 35%), in process (36% to 79%), or acquired (80% to 100%). The FAPI can be used in children as young as a few months of age and can continue to be used until "acquired" scores are obtained for all categories.

The Early Language Milestone scale (ELM) (Coplan, 1987) is a 43-item tool designed to assess language development in children from birth to 3 years. The tool has three sections focusing on expressive, receptive, and visual language. The ELM is typically administered via parental interview and based on parental report; however, there are sections for which clinician observation can also be used. Administration and scoring is estimated in the range of 3 to 10 min depending on the child's age, level of development, and scoring method (i.e., pass/fail or point scoring).

Individual clinics must determine which auditory questionnaires best meet the needs of their patient population and their families. What is more important than the actual questionnaires used is that the clinicians within a given program be consistent across all patients. However, as we move more toward a culture of evidence-based healthcare and patient-centered care, we must be prepared to benchmark our patients' outcomes against that reported in the literature. The way to ensure this is to use the recommended materials allowing for direct comparison. In doing so, the cochlear implant team members can closely monitor the auditory progress of children during the hearing aid trial period and beyond should a child receive cochlear implants being careful to describe and analyze the complete auditory profile and not fall into the trap of failing to see "beyond the audiogram."

STUDENTSHUB.com Uploaded By: tuka abuzneid

EVALUATION OF AUDITORY SKILLS AND PROGRESS IN PRESCHOOL TO SCHOOL-AGE CHILDREN

As with infants and toddlers, assessment of auditory skills and development for older children may not be well predicted by the audiogram. Although behavioral assessment of auditory skills should always be attempted for preschool and school-age children, due to a number of factors, behavioral assessment may not be possible or only very limited information may be obtained. For this reason, there are several auditory-skill questionnaires designed for use with preschool and school-age children.

The Meaningful Auditory Integration Scale (MAIS) (Robbins et al., 1991) is a 10-item parental interview-style questionnaire designed for assessing auditory skills including spontaneous responses to sounds for children age 3 to 5 years. All three cochlear implant manufacturers make reference to this questionnaire for determining auditory progress—or lack thereof—with appropriately fitted amplification.

The Parents' Evaluation of Aural/Oral Performance of Children (PEACH) is a 13-item questionnaire designed for parental estimation of the child's functional aural and oral abilities in everyday life (Ching & Hill, 2007). It is considered appropriate for children age 3 to 7 years. The PEACH asks parents to reflect on their child's listening behavior over the previous week and assigns a numerical value to parental answers ranging from 0 (never or 0%) to 4 (always or 75% to 100%). The PEACH includes questions relating to listening in both quiet and noisy surroundings.

The 23-item FAPCI questionnaire (Lin et al., 2007) can be administered to parents of children age 2 to 5 years. As stated previously, although the FAPCI was originally intended to track postoperative progress, using it during the candidacy process provides clinicians and families with a baseline against which future growth in auditory skills can be gauged. There are other general parent-based questionnaires available for use with children who have severe-to-profound sensory hearing loss, including Meaningful Use of Speech Sounds (MUSS) (Robbins & Osberger, 1990, Children's Home Inventory for Listening Difficulties (CHILD) (Anderson & Smaldino, 1999), and Developmental Index of Audition and Listening (DIAL; Palmer & Mormer, 1999). The questionnaires listed in Table 3–2 are those most frequently used with children both pre- and post-implantation. More important than the actual questionnaires used, however, is that individual

clinics determine the appropriateness of the different instruments for their patient population. What is most important is consistency across clinicians and patients within a cochlear implant program so that individual clinics can track the typical performance for children implanted at their center as well as benchmarking their patients' outcomes against those reported in the peer-reviewed literature.

Testing Conditions

As mentioned in Chapter 2, the testing conditions for determining cochlear implant candidacy are not widely agreed upon among clinicians. All implant manufacturers reference the "best-aided condition" for determining adult and pediatric candidacy. Clinicians may interpret the term "best-aided condition" differently. In the case of asymmetric hearing loss and/or speech recognition performance across the ears, the best-aided condition may be a gross overestimation of performance as compared with performance for the proposed ear to be implanted. The PMSTB recommends individual ear testing for pre- and post-implant assessment of performance. It is important to note, however, that it may not be possible to obtain individual ear estimates of speech recognition, particularly not in the same assessment visit. Nevertheless, it should remain a goal and one that is critical for children with asymmetric hearing loss.

Hearing Aids: Trial, Verification, and Evaluation of Speech and Language

STUDENTS-HUB.com Uploaded By: tuka abuzneid

The speech/language pathologist (SLP) plays a critical role in the cochlear implant candidate selection process for infants and children (also see Chapter 4). Often a child presenting for cochlear implant evaluation has little or no language in terms of either manual or spoken communication abilities. The evaluation of speech and language should be scheduled to coincide with a prior audiology appointment so that the hearing aid settings are verified. According to the American Academy of Audiology's Pediatric Amplification Protocol (2003), best practices requires that hearing aids be verified using either probe-microphone measurements or test-box verification with patient-specific real ear to coupler difference (RECD) corrections. Furthermore, given that nonlinear hearing aid circuitry is generally used to attain audibility at various input levels, a prescriptive formula, such as DSL v5.0 (Seewald, Ross, & Spiro, 1985; Cornelisse, Seewald, & Jamieson, 1995; Scollie et al., 2005), should be used to verify target audibility at speech-input levels corresponding to soft, average, and loud, such as 50, 60, and 70 dB SPL.

When beginning a hearing aid trial for infants who are thought to meet cochlear implant candidacy based on the severity of the hearing loss, it is critical to also schedule a speech/language assessment to determine baseline language skills against which future development can be measured. The specific metrics used by the SLP are dependent on both the chronologic age as well as the "hearing" age of the child (see Chapter 4). During the hearing aid trial period, it is expected that the child demonstrate *at least* month-for-month progress in auditory skills as well as speech and language developmental progress with amplify in order to derive appropriate benefit from hearing aids. What that means is that if a child has been fitted with hearing aids for 6 months, they should demonstrate *at least* 6 months of progress in auditory skills and speech/language development. If this is not the case for a child making full-time use of amplify and appropriate intervention—in the absence of developmental delay and/or cognitive concerns—then cochlear implantation must be considered.

It is recommended that a child receive at least two speech/language evaluations during the candidacy selection process during the hearing aid trial. Although it likely not be possible to administer norm-referenced measures over such a short period of time (see Chapter 8), there are many criterion-referenced measures that are available and can provide valuable information about a child's progress with appropriately fitted hearing aids.

It is crucial that children receive appropriate intervention including regular visits from a member of the early intervention team, speech/

Table 3–2. Questionnaires Most Frequently Used with Children Both Pre- and Postimplantation

Measure Name	*Length and Estimated Time to Complete*	*Domains Assessed*	*Age Range*	*Administration*
LittlEARS[a]	35 yes/no items; 5 to 7 min	Age appropriateness of auditory behaviors (e.g., responsiveness to acoustic rituals, looking for sound sources)	0 to 24 months	Independent parental completion; parental report; PMSTB recommended
Auditory Skills Checklist	35 items; <10 min	Detection, discrimination, identification, and comprehension	0 to 36 months	Parental interview; clinician observation; PMSTB recommended
Early Language Milestones (ELM)	43 items; <10 min	Auditory-based language behaviors (expressive, receptive, and visual)	0 to 36 months	Parental report; direct observation
Infant–Toddler Meaningful Auditory Integration Scale (IT-MAIS)	10 items; 5 to 10 min	Device bonding, alerting to sound, vocalization, deriving meaning from sound	0 to 36 months	Parental interview
Functioning After Pediatric Cochlear Implantation (FAPCI)	23 items; 5 to 10 min	Speech intelligibility, auditory responsiveness, real-world verbal communication	2 to 5 years	Independent parental completion; parental report
Functional Auditory Performance Indicators (FAPI)	33 items; 10 to 15 min	Auditory awareness, feedback and integration, discrimination, comprehension, memory, and linguistic processing	3 months until "acquired" is obtained for all categories	Parental interview; parental report; direct observation
Meaningful Auditory Integration Scale (MAIS)	10 items; 5 to 10 min	Device bonding, alerting to sound, vocalization, deriving meaning from sound	3 to 5 years	Parental interview
Parents' Evaluation of Aural/Oral Performance of Children (PEACH)	13 items; 5 to 10 min	Aural/oral speech communicative behaviors in quiet and noisy situations	3 to 7 years	Independent parental completion; parental report

[a]MED-EL, Innsbruck, Austria.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

language therapy, as well as active parental involvement to supplement therapy with proper modeling of spoken-language development. The cochlear implant team can glean considerable information from parental compliance to not only full-time use of amplification but also to the recommended therapy schedule during the candidacy selection process. It sets an important precedent for what will be expected following cochlear implant surgery, as intensive intervention

and therapy will be required if the child is to make full use of the audibility provided by the new, electrical signal. More detailed information regarding the role of the SLP in the determination of pediatric cochlear implant candidacy is provided in Chapter 4.

Role of the Social Worker and/or Psychologist in the Determination of Cochlear Implant Candidacy

The role of the social worker and/or psychologist in the determination of cochlear implant candidacy can be extremely valuable for pediatric candidates and their families. A psychological evaluation, particularly a developmental psychological evaluation, may be recommended by the cochlear implant team in the event that concerns are raised regarding the overall cognitive and global developmental functioning of the child. Other areas in which a psychologist and/or social worker can provide valuable assistance is for families struggling with the diagnosis and implications of having a child who will be dependent on technology for hearing and communication. Other areas within the scope of the psychologist and/or social worker in determining implant candidacy include evaluation of family dynamics and level of dedication to the recommended postoperative therapy schedule. Such guidance can be sought after and/or recommended by the cochlear implant team pre- and post-implant, as needed.

An additional area in which a social worker can provide counseling and support for families is that of finances as related to medical care surrounding aural habilitation. Families may be unaware of the resources available to them for insurance coverage of medical care, therapy, and assistive listening devices. Social workers not only provide this information but also help provide access to the appropriate paperwork and help families navigate through the application processes, which can be daunting. In some cases, social workers can help families coordinate medical and therapy appointments, as well as review the past and current schedule of appointments to ensure that all medical specialties and evaluations have been made available to the family.

MEDICAL AND SURGICAL ISSUES

The cochlear implant surgeon, typically an otologist or neuro-otologist, clearly plays a vital role in the determination of implant candidacy (also see Chapter 5). Surgeons perform a thorough preoperative examination in addition to being responsible for the surgical procedure and postoperative otologic medical care. The otologist and his or her medical team also ensure that all cochlear implant candidates are current on recommended immunizations prior to surgery. The recommended immunizations for children undergoing cochlear implantation can be found on the Centers for Disease Control website: https://www.cdc.gov/vaccines/vpd/mening/public/dis-cochlear-faq-gen.html and includes, at a minimum, an age-specific pneumococcal vaccination. For children up to 18 years of age, the pneumococcal conjugate vaccination is marketed under the name Prevnar 13 (Wyeth Pharmaceuticals [Pfizer], New York, NY), and at the time of chapter preparation, it protects against 13 strains of pneumococcal infection. For children over 5 to 6 years of age, physicians may also recommend pneumococcal conjugate vaccine 23 (PCV23 or Pneumovax 23, Merck & Co., West Point, PA), which is known to protect against 23 of the most common strains of pneumococcal infection.

As with adult candidates, the otologist orders a preanesthetic medical evaluation or preoperative evaluation to ensure that the candidate is able to undergo surgery and the associated anesthetic risk. The preoperative evaluation includes assessment of vital signs and general medical evaluation to identify the presence of health problems that may affect peri and/or postanesthetic care. Furthermore, the otologist typically refers children to ophthalmology as well as medical genetics, because approximately 40% of children with sensorineural hearing loss have other medical and/or developmental comorbidities, including cognitive, visual, motor, behavioral, and learning (Fortnum, Marshall, & Summerfield, 2002; Gallaudet Research Institute, 2008; Roberts & Hindley, 1999; Van Naarden, Decoufle, & Caldwell, 1999). The otologist also refers to additional medical specialties such as neurology, physical medicine and

STUDENTS-HUB.com Uploaded By: tuka abuzneid

rehabilitation, and developmental pediatrics, as needed.

Otologists also routinely order imaging studies, including computed tomography (CT) and/or magnetic resonance imaging (MRI) to determine cochlear patency, as well as to rule out cochlear or other temporal bone anomalies that could impact the surgical insertion of the device. Cochlear and temporal bone anomalies are not necessarily contraindicated for cochlear implantation; however, preoperative awareness of such issues provides the best preparation for implant device selection and proposed surgical technique. High-resolution CT is generally ordered for all patients having met audiologic criteria for cochlear implantation. MRI is generally ordered for pediatric patients who have exhibited no behavioral hearing via audiometric testing and/or who are suspect for cochlear nerve deficiency. It is within the protocol for many cochlear implant programs that MRI is ordered for all pediatric patients prior to implantation. Though postoperative MRI up to 3.0 T is currently approved without magnet removal for both Advanced Bionics and MED-EL as up to 1.5 T for Cochlear (and up to 3.0 T for Cochlear with magnet removal), many otologists consider preoperative MRI valuable as a last chance to obtain detailed imaging information regarding the cochleovestibular nerve without artifact caused by the internal device.

UTILITY OF PREDICTIVE VARIABLES FOR POSTOPERATIVE OUTCOMES

Once a family is informed that their child is a candidate for cochlear implantation, in-depth counseling and education is critical. Just as discussed in Chapter 2 for adult candidates, pre-implant counseling is directly within the scope of the audiologist and constitutes a significant portion of each pediatric cochlear implant evaluation. As important as educating the family about the function of cochlear implants and what they do is the focus on what implants *cannot* do, such as restore "normal" hearing and auditory function.

Perhaps the most frequent question that families ask regarding cochlear implantation for their child is how well he or she will do with listening and spoken language—particularly with respect to a child's normal-hearing peers. There are a number of potential factors affecting postoperative outcomes, including wear time, intervention, preimplant audiometric thresholds, integrity of cochlear and neural structures, and etiology.

Age at Implantation

Age at implantation directly affects outcomes. As mentioned previously, there is a growing body of literature documenting a relatively narrow critical period for cochlear implantation for the development of listening and spoken language (Hayes et al., 2009; Moog & Geers, 2010; Bergeson et al., 2010; Niparko et al., 2010; Habib et al., 2010; Houston & Miyamoto, 2010; Houston, Stewart, et al., 2012, Houston, Beer, et al., 2012; Dettman et al., 2016; Tobey et al., 2013), as well as auditory pathway maturation (Ponton et al., 2000; Sharma et al., 2002; Eggermont et al., 2003; Gordon et al., 2005; Kral et al., 2006; Sharma & Dorman, 2006; Gilley et al., 2008; Sharma et al., 2009). Houston and colleagues have shown significantly better word learning abilities in infants implanted under 13 months of age (Houston, Stewart, et al., 2012, Houston, Beer, et al., 2012; Houston & Miyamoto, 2010) as compared to children implanted between 16 and 23 months of age. Other studies have shown that children implanted in the range of 18 to 24 months of age demonstrate significantly greater language and vocabulary development—both expressive and receptive—than children implanted over 2 years of age (Hayes et al., 2009; Niparko et al., 2010; Artières, Vieu, Mondain, Uziel & Venail, 2011; Quittner et al., 2011; Boons et al., 2012; Tobey et al., 2013; Dettman et al., 2016).

Despite the relationship between age at implantation and auditory/oral language outcomes, children implanted over 18 to 24 months of age still derive significant benefit; however, family counseling regarding expectations needs to be realistic with the child's age at activation noted as a critical variable. In other words, clinicians should counsel that more aggressive intervention might be needed for the child implanted over 2 years of age for whom the family's goal remains

STUDENTS-HUB.com Uploaded By: tuka abuzneid

auditory/oral language with high levels of speech intelligibility.

Wear Time

Cochlear implants provide access to sound for children; however, the processor(s) must be worn all waking hours in order to derive maximum benefit. The Alexander Graham Bell Association for the Deaf and Hard of Hearing has provided powerful examples highlighting the need for consistent device use. An infant with normal hearing typically listens for 10 hours per day, totaling at least 3,650 hours of listening over the first year of life. For the infant making only part-time use of hearing aids during the candidacy process (estimated at 4 hours per day) it would take 6 years to provide as much listening experience as that of a baby with normal hearing or a baby who wears hearing aids and/or implant sound processors all waking hours (Stovall, 1982; Rossi, 2003). A toddler/preschooler with normal hearing is estimated to be listening approximately 12 hours per day. Over the course of a year, that equals 4,380 hours of listening. For the toddler/preschooler wearing the implant sound processors on a part-time basis, such as 2.75 hours per day while at preschool, it would take 9 years to provide as much listening experience that is gained over a single year for the child with normal hearing or the child making full-time use of the sound processors (Rossi, 2003).

Although age at implantation is a critical variable regarding outcomes, if full-time usage of the sound processor(s) is not enforced, *progress will not be made*. The importance of wear time is a critical counseling tool and one that stands repeating multiple times during preoperative counseling as well as at postoperative follow-up appointments. Indeed, since the availability of data logging for cochlear implant sound processors, there have been a number of peer-reviewed papers demonstrating the wide variability in wear time for infants and children with cochlear implants (Busch, Vanpoucke, & van Wieringen, 2017; Easwar, Sanfilippo, Papsin, & Gordon, 2016, 2018) ranging from just over 2 hours per day up to nearly 18 hours per day in early childhood. Recent studies have demonstrated a significant correlation between average daily wear time and speech recognition (Easwar et al., 2018) and development of auditory skills (Guerzoni & Cuda, 2017). With time, we will gain a better understanding of the relationship between daily wear time and outcomes.

Intervention

The best outcomes are not simply achieved with early implantation and processor wear time. It has been repeatedly documented that the highest levels of auditory/oral language outcomes are achieved in conjunction with early and consistent intervention, focusing on listening and spoken language (e.g., Nicholas & Geers, 2007; Geers, Moog, Biedenstein, Brenner, & Hayes 2009; Moeller, 2000; Moog & Geers, 2010; Tobey, Shin, Sundarrajan & Geers, 2011). Higher levels of receptive and expressive language of school-age children with cochlear implants are associated with early enrollment in comprehensive intervention programs, including those incorporating parental/family involvement and focusing on listening and spoken language (Moeller, 2000; Moog & Geers, 2010; Langereis & Vermeulen, 2015; Geers et al., 2017). It must be stressed to families that the work does not end with the surgical placement of the implant. In other words, cochlear implants do not "cure" hearing loss. Rather, the hardest work begins once the implant has been activated. The best outcomes are achieved with intensive habilitation, including regular speech/language therapy, continuation of infant and family services with home-based infant/family specialists, enrollment in parent–infant programs, and later involvement in a preschool program focusing on listening and spoken language; thus, it is actually the case that implant surgery and activation represent only the first steps in the journey.

It is noteworthy that an auditory/oral approach to communication may not be the goal of every family, nor may it be a reasonable expectation based on the age of identification, age at implantation, family dynamics, and/or other developmental delays associated with the underlying etiology or comorbidities. There are other modes

STUDENTS-HUB.com Uploaded By: tuka abuzneid

of communication incorporating signing, cued speech, augmentative communication, or any combination thereof. Keeping the family's goals in view is paramount, with an eye toward reasonable expectations, which will allow for the highest level of family-centered counseling and overall satisfaction.

Preimplant Audiometric Thresholds

Audiologists and surgeons tend to place considerable emphasis on the audiogram and audiometric thresholds; however, although the audiogram represents a diagnostic measure of an individual's auditory detection or *sensation*, it does not always accurately reflect an individual's auditory function or *perception*—particularly not for children with congenital hearing loss. Given that children receiving cochlear implants typically have bilateral severe-to-profound hearing loss, there exists a very narrow range of preoperative audiometric thresholds with which to correlate postoperative performance. As discussed in Chapter 2, for adult predictive variables of postoperative performance, there are no studies which show a definitive relationship between preoperative audiometric thresholds and postoperative outcomes for pediatric implant recipients.

Integrity of Cochlear and Neural Structures

Any structural anomaly involving the bony labyrinth, cochlear lumen, or internal auditory canal has the potential to affect postoperative outcomes. It has been stated that up to 35% of children with sensorineural hearing loss have cochleovestibular anomalies (Papsin, 2005). Common structural abnormalities that one might expect to uncover in the pediatric population include Mondini dysplasia, common cavity, enlarged vestibular aqueduct, and atretic internal auditory canal. All of these diagnoses are observable via CT and would thus be diagnosed prior to implantation for pediatric candidates, provided that the temporal bone CT protocol had been completed.

Cochlear nerve deficiency (CND) is another structural abnormality that may be discovered for a child diagnosed with profound sensorineural hearing loss. CND refers to cases in which the auditory nerve is either absent or hypoplastic. In cases of CND for which the auditory nerve is absent, cochlear implantation is contraindicated because the presence of an auditory nerve is a vital prerequisite given that the primary auditory neurons, located within the modiolus, and generally referred to as spiral ganglion cells, are the targets for electrical stimulation via the implanted intracochlear electrodes. Cases of CND for which the auditory nerve is hypoplastic are associated with poorer postoperative outcomes; however, cochlear implantation can offer significant communicative benefit not realized via amplification (Teagle et al., 2010; Buchman et al., 2011; Seymour et al., 2010; Zhang et al., 2012; Vincenti et al., 2014; Peng et al., 2017; He et al., 2018; Kari et al., 2018; Han et al., 2019). CND is observable via MRI and would be diagnosed prior to implantation for pediatric candidates, provided that MRI with the temporal bone protocol had been completed. There are now a number of clinical trials investigating efficacy of cochlear implantation first, followed by auditory brainstem implantation in cases of CND that were unresponsive to cochlear implantation (Vesseur et al., 2018; Colletti et al., 2013, 2014).

Auditory neuropathy is another issue that may affect postoperative outcomes. Auditory neuropathy can manifest as a true neuropathy of cranial nerve VIII, which is generally observed along with other peripheral neuropathies, or an auditory neuropathy spectrum disorder (ANSD)—the latter of which is frequently associated with pediatric cases of auditory neuropathy. For more details on the audiometric profile characteristic of ANSD, see Chapter 2.

Auditory neuropathy including peripheral nerve damage has the potential to negatively impact outcomes; in fact, peripheral auditory neuropathy would preclude cochlear implant candidacy as the criterion of intact auditory nerve would not be met. However, it may be difficult to definitively diagnose auditory neuropathy from ANSD preoperatively—particularly for very young children—and thus our counseling and expectations need to recognize the possibility. True auditory

STUDENTS-HUB.com Uploaded By: tuka abuzneid

neuropathy is rare in the pediatric population such that when present, it is most frequently a diagnosis secondary to a primary peripheral neuropathy, such as that associated with Charcot-Marie-Tooth disease.

Etiology

Just as with adult patients, the etiology of hearing loss for a large proportion of pediatric patients is largely unknown. It is estimated that approximately half of all congenital hearing losses have an underlying genetic component, though this estimate will likely increase as human genome research continues (Rehm, 2005). For a large proportion of pediatric patients, there is generally no concern about etiology affecting counseling for postoperative outcomes. There are, however, some etiologies which are known to potentially affect postoperative outcomes for pediatric cochlear implant recipients. Although certainly not exhaustive, the most common etiologies and associated concerns regarding outcomes are covered here.

Meningitis

The incidence of bacterial meningitis is significantly higher in children than in adults and accounts for approximately 6% of cases of acquired sensorineural hearing loss in childhood (Smith et al., 2005). The pneumococcal conjugate vaccine has significantly reduced the incidence of bacterial meningitis in children; however, for those that do contract meningitis, approximately 5% to 10% of cases experience severe-to-profound sensorineural hearing loss (Baraff, Lee, & Schriger, 1993; Smith et al., 2005). As mentioned in Chapter 2, the underlying cause of hearing loss associated with bacterial meningitis is the development of labyrinthitis, loss of hair cells, spiral ganglion cell degeneration, and cochlear ossification (Lu & Schuknecht, 1994; Nadol & Hsu, 1991). See Chapter 2 for more information regarding meningitis and projected outcomes.

Syndrome-Related Deafness

There are a number of syndromes known to be associated with various degrees of sensorineural hearing loss. There are numerous reports of successful outcomes with cochlear implantation in children with syndromic hearing loss, including branchial-oto-renal syndrome, CHARGE syndrome, Pendred syndrome, Refsum disease, Usher syndrome, and Waardeburg syndrome (e.g., Loundon, Marlin, Busquet, Denoyelle, Roger, Renaud, & Garabedian 2003; Raine, Kurukulasuriva, Bajaj, & Strachan, 2008; Cullen, Zdanski, Roush, Brown, Teagle, Pillsbury, & Buchman, C. 2006; Vescan, Parnes, Cucci, Smith, & MacNeill, 2002; Arndt et al., 2010; Lina-Granade, Porot, Vesson, & Truy, 2010). Those syndromes known also to be related to progressive loss of vision, such as Usher syndrome and Refsum disease, can particularly affect outcomes, as speech/language therapy makes use of visual cues. Even auditory/oral language development has a strong nonverbal component, and thus, early implantation prior to the onset of significant visual loss is recommended. Syndromes having the potential to impact global development and cognition, such as CHARGE, also expectedly impact outcomes, and thus require extensive preimplant counseling regarding appropriate expectations.

Chromosome-Related Deafness

The chromosomal condition most commonly linked with sensorineural hearing loss is Trisomy 21, more commonly referred to as Down syndrome. Down syndrome is associated with sensorineural hearing loss in approximately 5% to 20% of cases with severe-to-profound deafness present in 5% or fewer cases (Roizen, Wolters, Nicol, & Blondis, 1993; Hans, England, Prowse, Young & Sheehan, 2010). For those children with Down syndrome and significant sensorineural hearing loss, however, cochlear implantation remains a viable treatment option (Hans et al., 2010; Phelan et al., 2016). Expectations for progress following cochlear implantation are directly related to the cognitive status of the individual, which can vary widely with Down syndrome, as well as the increased risk for middle ear disease. Given the propensity for middle ear disease in children with Down syndrome, it is particularly important that appropriate vaccinations are up to date.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Other Variables Affecting Postoperative Outcomes

In recent years there have been several multicenter longitudinal studies examining postoperative outcomes for pediatric implant recipients (e.g., Niparko et al., 2010; Barker et al., 2009; Geers, Brenner, & Davidson, 2003; Szagun & Stumper, 2012; Liu et al., 2015; Dettman et al., 2016; Geers et al., 2017). Other than the expected variables, such as duration of hearing loss prior to implantation, age at implantation, early intervention, educational placement, postoperative degree of audibility with implants, and others, there are a number of associated variables related to family/social issues. Those variables found to be related to outcomes for language development and speech recognition are family size, intelligence, socioeconomic status, maternal level of education, and the amount of time spent talking to the child at home (sometimes referred to as language exposure). Some of these predictive variables, such as family size, maternal level of education, and socioeconomic status, are not necessarily appropriate to discuss during preoperative counseling. The variable that should be discussed at length by the audiologist, speech/language pathologist, deaf educator, and early-intervention specialist is the amount of time spent talking to the child at home. These behaviors should be started well before the surgery date, setting a precedent and learned behavior/habit of incorporating language modeling and functional auditory/oral communication throughout the day.

CONCLUSION

Cochlear implants have been shown to change the course of a child's life, potentially allowing for age-normative development of speech, language, and literacy. Even for those children not able to achieve an auditory/oral approach to speech and language, cochlear implants provide sound awareness increasing safety and quality of life for the recipient. It is important to recognize that pediatric candidacy criteria have dramatically evolved over the past several decades, and that cochlear implants are no longer only for children with profound deafness. The interdisciplinary cochlear implant team offers patients the highest level of care and information needed to progress through the candidacy selection process.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

Alzhrani, F., Yousef, M., Almuhawas, F., & Almutawa, H. (2019). Auditory and speech performance in cochlear implanted ANSD children. *Acta Otolaryngologica*, *5*, 1–5.

American Academy of Audiology. (2003). *Pediatric amplification protocol.* Retrieved May 2, 2012, from http://www.audiology.org

Anderson, K., & Smaldino, J. (1999). Listening inventories for education: A classroom measurement tool. *The Hearing Journal, 52*(10), 74–75.

Arndt, A., Laszig, R., Beck, R., Schild, C., Maier, W., Birkenhager, R., . . . Aschendorff, A. (2010). Spectrum of hearing disorders and their management in children with CHARGE syndrome. *Otology & Neurotology, 31*, 67–73.

Artières, F., Vieu, A., Mondain, M., Uziel, A., & Venail, F. (2009). Impact of early cochlear implantation on the linguistic development of the deaf child. *Otology & Neurotology, 30*(6), 736–742.

Baraff, L. J., Lee, S. I., & Schriger, D. L. (1993). Outcomes of bacterial meningitis in children: A meta-analysis. *Pediatric Infections and Disorders Journal, 12*(5), 389–394.

Barker, D. H., Quittner, A. L., Fink, N. E., Eisenberg, L. S., Tobey, E. A., & Niparko, J. K. (2009). CDaCI Investigative Team. Predicting behavior problems in deaf and hearing children: The influences of language, attention, and parent-child communication. *Developmental Psychopathology, 21*(2), 373–392.

Bergeson, T. R., Houston, D. M., & Miyamoto, R. T. (2010). Effects of congenital hearing loss and cochlear implantation on audiovisual speech perception in infants and children. *Restorative Neurology and Neuroscience, 28*, 157–165.

Bess, F. H., Sinclair, J. S, & Riggs, D. (1984). Group amplification in schools for the hearing impaired. *Ear and Hearing, 5*, 138–144.

Boons, T., Brokx, J. P., Dhooge, I., Frijns, J. H., Peeraer, L., Vermeulen, A., et al. (2012). Predictors of spoken language development following pediatric cochlear implantation. *Ear and Hearing, 33*(5), 617–639.

Boothroyd A. (1984). Auditory perception of speech contrasts by subjects with sensorineural hearing loss. *Journal of Speech and Hearing Research*, 27, 134–144.

Breneman, A. I., Gifford, R. H., & Dejong, M. D. (2012). Cochlear implantation in children with auditory neuropathy spectrum disorder: Long-term outcomes. *Journal of the American Academy of Audiology*, *23*(1), 5–17.

Buchman, C. A., Teagle, H. R., Roush, P. A., Park, L. R., Hatch, D., Woodard, J., . . . Adunka, O. F. (2011). Cochlear implantation in children with labyrinthine anomalies and cochlear nerve deficiency: Implications for auditory brainstem implantation. *Laryngoscope, 121*, 1979–1988.

Busch, T., Vanpoucke, F., & van Wieringen, A. (2017). Auditory environment across the life span of cochlear implant users: Insights from data logging. *Journal of Speech-Language-Hearing Research*, *60*(5), 1362–1377.

Carhart, R. (1946). Monitored live-voice as a test of auditory acuity. *Journal of the Acoustical Society of America, 17*, 339–349.

Carlson, M. L., Sladen, D. P., Haynes, D. S., Driscoll, C. L., DeJong, M. D., Erickson, H. C., . . . Gifford, R. H. (2014). Evidence for the expansion of pediatric cochlear implant candidacy. *Otology and Neurotology*. https://doi.org/10.1097/MAO.0000000000000607

Ching, T. Y., & Hill, M. (2007). The parents' evaluation of aural/oral performance of children (PEACH) scale: Normative data. *Journal of the American Academy of Audiology, 18*(3), 220–235.

Clark, W. W., & Govett, S. B. (1995). *School-related noise exposure in children.* Paper presented at the Association for Research in Otolaryngology Mid-Winter Meeting, St. Petersburg, FL.

Colletti, L., Colletti, G., Mandalà, M., & Colletti, V. (2014). The therapeutic dilemma of cochlear nerve deficiency: Cochlear or brainstem? *Otolaryngology-Head and Neck Surgery*, *151*(2), 308–314.

Colletti, L., Wilkinson, E. P., & Colletti, V. (2013). Auditory brainstem implantation after unsuccessful cochlear implantation of children with clinical diagnosis of cochlear nerve deficiency. *Annals of Otology Rhinology and Laryngology*, *122*(10), 605–612.

Coninx, F., Weichbold, V., Tsiakpini, L., Autrique, E., Bescond, G., Tamas, L., . . . Brachmaier, J. (2009). Validation of the LittlEARS auditory questionnaire in children with normal hearing. *International Journal of Pediatric Otorhinolaryngology, 73*(12), 1761–1768.

Coplan, J. (1987). *ELM scale: The early language milestone scale.* Austin, TX: Pro-Ed.

Cornelisse, L., Seewald, R., & Jamieson, D. (1995). The input/output formula: A theoretical approach to the fitting of personal amplification devices. *Journal of the Acoustical Society of America, 97*(3), 1854–1864.

Cosetti, M., Roland, J. T. Jr. (2010). Cochlear implantation in the very young child: issues unique to the under-1 population. *Trends in Amplification*, *14*(1), 46–57.

Crukley, J., Scollie, S., Parsa, V. (2011). An exploration of non-quiet listening at school. *Journal of Educational Audiology, 17*, 23–35.

Cullen, R. D., Zdanski, C., Roush P, Brown, C., Teagle, H., Pillsbury, H., & Buchman, C. (2006). Cochlear implants in Waardenburg syndrome. *Laryngoscope, 116*, 1273–1275.

Dettman, S. J., Dowell, R. C., Choo, D., Arnott, W., Abrahams, Y., Davis, A., . . ., Briggs, R. J. (2016). Long-term communication outcomes for children receiving cochlear implants younger than 12 months: A multicenter study. *Otology & Neurotology, 37*(2), e82–95.

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2016). Factors affecting daily cochlear implant use in children: Data logging evidence. *Journal of the American Academy of Audiology 27*(10), 824–838.

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2018). Impact of consistency in daily device use on speech perception abilities in children with cochlear implants: Datalogging evidence. *Journal of the American Academy of Audiology*, *29*(9), 835–846.

Eggermon, J. J., & Ponton, C. W. (2003). Auditory-evoked potential studies of cortical maturation in normal hearing and implanted children: Correlations with changes in structure and speech perception. *Acta Oto-laryngologica*, *123*(2), 249–252.s

Eilers, R. E., Morse, P. A., Gavin, W. J., & Oller, D. K. (1981). Discrimination of voice onset time in infancy. *Journal of the Acoustical Society of America*, *70*, 955–965.

Eilers, R. E., Wilson, W. R., & Moore, J. M. (1977). Developmental changes in speech discrimination in infants. *Journal of the Acoustical Society of America*, *20*, 766–780.

Etymotic Research. (2005). Bamford-Kowal-Bench Speech-in-Noise Test (Version 1.03) [Audio CD]. Elk Grove Village, IL: Author.

Finitzo-Hieber, T. (1988). Classroom acoustics. In R. Roeser (Ed.), *Auditory disorders in school children* (2nd ed., pp. 221–223). New York, NY: Thieme-Stratton.

Fortnum, H. M., Marshall, D. H., & Summerfield, A. Q. (2002). Epidemiology of the UK population of hearing-impaired children, including characteristics of those with and without cochlear implants—audiology, aetiology, comorbidity and affluence. *International Journal of Audiology*, 41(3), 170–179.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Gallaudet Research Institute. (2008). *Regional and national summary report of data from the 2008 annual survey of deaf and hard of hearing children and youth.* Washington, DC: Gallaudet University.

Geal-Dor, M., Jbarah, R., Meilijson, S., Adelman, C., & Levi, H. (2011). The Hebrew and the Arabic version of the LittlEARS® auditory questionnaire for the assessment of auditory development: results in normal hearing children and children with cochlear implants. *International Journal of Pediatric Otorhinolaryngology, 75*(10), 1327–1332.

Geers, A., Brenner, C., & Davidson, L. (2003). Factors associated with development of speech perception skills in children implanted by age five. *Ear and Hearing, 24*, 24S–35S.

Geers, A. E., Mitchell, C. M., Warner-Czyz, A. Wang, N. Y., Eisenberg, L. S. and the CDACI Investigative Team. (2017). Early sign language exposure and cochlear implantation benefits. *Pediatrics, 140*(1), e20163489.

Geers, A. E., Moog, J. S., Biedenstein, J., Brenner, C., & Hayes, H. (2009). Spoken language scores of children using cochlear implants compared to hearing age-mates at school entry. *Journal of Deaf Studies and Deaf Education, 14*, 371–385.

Gelnett, D., Sumida, A., Nilsson, M., & Soli, S. D. (1995). *Development of the hearing-in-noise test for children (HINT-C).* Paper presented at the annual meeting of the American Academy of Audiology, Dallas, TX.

Gilley, P. M., Sharma, A., & Dorman, M. F. (2008). Cortical reorganization in children with cochlear implants. *Brain Research, 1239*, 56–65.

Gordon, K. A., Papsin, B. C., & Harrison, R. V. (2005). Effects of cochlear implant use on the electrically evoked middle latency response in children. *Hearing Research*, *204*(1–2), 78–89.

Gordon, K. A., Papsin, B. C., & Harrison, R. V. (2006). An evoked potential study of the developmental time course of the auditory nerve and brainstem in children using cochlear implants. *Audiology & Neurotology, 11*(1), 7–23.

Gravel, J. S., White, K. R., Johnson, J. L., Widen, J. E., Vohr, B. R., James, M., . . . Meyer, S. (2005). A multisite study to examine the efficacy of the otoacoustic emission/ automated auditory brainstem response newborn hearing screening protocol: Recommendations for policy, practice, and research. *American Journal of Audiology, 14*(2), S217–S228.

Greenberg, J. H., & Jenkins, J. J. (1964). Studies in the psychological correlates of the sound system of American English. *Word*, 20, 157–177.

Guerzoni, L., & Cuda, D. (2017). Speech processor data logging helps in predicting early linguistic outcomes in implanted children. *International Journal of Pediatric Otorhinolaryngology, 101*, 181–186.

Habib, M. G., Waltzman, S. B., Tajudeen, B., & Svirsky, M. A. (2010). Speech production intelligibility of early implanted pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology, 74*, 855–859.

Han, J. J., Suh, M. W., Park, M. K., Koo, J. W., Lee, J. H., & Oh, S. H. (2019). A predictive model for cochlear implant outcome in children with cochlear nerve deficiency. *Scientific Reports*, *9*(1), 1154. http://dx.doi: 10.1038/s41598-018-37014-7

Hans, P. S., England, R., Prowse, S., Young, E., & Sheehan, P. Z. (2010). UK and Ireland experience of cochlear implants in children with Down syndrome. *International Journal of Pediatric Otorhinolaryngology, 74*, 260–264.

Haskins, H. (1949). *A phonetically balanced test of speech discrimination for children*. Unpublished master's thesis. Northwestern University, Evanston, IL.

Hayes, H., Geers, A. E., Treiman, R., & Moog, J. S. (2009). Receptive vocabulary development in deaf children with cochlear implants: achievement in an intensive auditory-oral educational setting. *Ear and Hearing, 30*, 128–135.

He, S., Shahsavarani, B. S., McFayden, T. C., Wang, H., Gill, K. E., Xu, L., Chao, X., . . . He, N. (2018). Responsiveness of the electrically stimulated cochlear nerve in children with cochlear nerve deficiency. *Ear and Hearing*, *39*(2), 238–250.

Holman, M.A., Carlson, M. L., Driscoll, C. L., Grim, K. J., Peetersson, R. S., Sladen, D. P., & Flick, R. P. (2013). Cochlear implantation in children 12 months of age and younger. *Otology & Neurotology, 34*(2), 251–258.

Houston, D. M., & Miyamoto, R. T. (2010). Effects of early auditory experience on word learning and speech perception in deaf children with cochlear implants: implications for sensitive periods of language development. *Otology & Neurotology*, 31(8), 1248–1253.

Houston, D. M., Stewart, J., Moberly, A., Hollich, G., & Miyamoto, R. T. (2012). Word learning in deaf children with cochlear implants: effects of early auditory experience. *Developmental Science*, 15(3), 448–461.

Houston, D. M., Beer, J., Bergeson, T. R, Chin, S. B., Pison,i D. B., & Miyamoto, R. T. (2012). The ear is connected to the brain: some new directions in the study of children with cochlear implants at Indiana University. *Journal of the American Academy of Audiology*, *23*(6), 446–463.

Houston, D. M., & Jusczyk, P. W. (2003). Infants' long-term memory for the sound patterns of words and voices. *Journal of Experimental Psychology: Human Perception and Performance, 29*(6), 1143–1154.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Jerger, S., Lewis, S., Hawkins, J., & Jerger, J. (1980). Pediatric Speech Intelligibility Test I. Generation of test materials. *International Journal of Pediatric Otorhinolaryngology, 2*(3), 217–230.

Jerger, S., & Jerger, J. (1984). Pediatric speech intelligibility Test. St. Louis, MO: Auditec

Jusczyk, P. W. (2002). Some critical developments in acquiring native language sound organization during the first year. *Annals of Otology, Rhinology and Laryngology Supplement*, 189, 11–15.

Jusczyk, P. W., & Hohne, E. A. (1997). Infants' memory for spoken words. *Science, 277*(5334), 1984–1986.

Kari, E., Go, J. L., Loggins, J., Emmanuel, N., & Fisher, L. M. (2018). Abnormal cochleovestibular anatomy and hearing outcomes: Pediatric patients with a questionable cochleovestibular nerve status may benefit from cochlear implantation and/or hearing aids. *Audiology & Neuro-otology*, *23*(1), 48–57.

Kim, L. S., Jeong, S. W., Lee, Y. M., & Kim, J. S. (2010). Cochlear implantation in children. *Auris Nasus Larynx, 37*(1), 6–17.

Kirk, K. I., Pisoni, D. B., & Osberger, M. J. (1995). Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear and Hearing, 16*, 470–481.

Kral, A., Tillein, J., Heid, S., Klinke, R., & Hartmann R. (2006). Cochlear implants: Cortical plasticity in congenital deprivation. *Progress in Brain Research, 157*, 283–313.

Kruel, E., Bell, D., & Nixon, J. (1969). Factors affecting speech discrimination test difficulty. *Journal of Speech and Hearing Research, 12*, 281–287.

Landauer, T. K., & Streeter, L. A. (1973). Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *Journal of Verbal Learning and Verbal Behavior, 12*, 119–131.

Langereis, M., & Vermeulen, A. (2015). School performance and wellbeing of children with CI in different communicative-educational environments. *International Journal of Pediatric Otorhinolaryngology, 79*(6), 834–839.

Leigh, J. R., Dettman, S. J., & Dowell, R. C. (2016). Evidence-based guidelines for recommending cochlear implantation for young children: Audiological criteria and optimizing age at implantation. *International Journal of Audiology*, *55 (*Suppl. 2*)*, S9–S18.

Levine, D., Strother-Garcia, K., Golinkoff, R. M., & Hirsh-Pasek, K. (2016). Language development in the first year of life: What deaf children might be missing before cochlear implantation. *Otology & Neurotology*, *37*(2), e56–62.

Lin, F. R., Ceh, K., Bervinchak, D., Riley, A., Miech, R., & Niparko, J. K. (2007). Development of a communicative performance scale for pediatric cochlear implantation. *Ear and Hearing*, *28*(5), 703–712.

Lina-Granade, G., Porot, M., Vesson, J. F., & Truy, E. (2010). More about cochlear implantation in children with CHARGE association. *Cochlear Implants International, 11*(Suppl. 1), 187–191.

Liu, H., Liu, S., Kirk, K. I., Zhang, J., Ge, W., Zheng, J., . . ., Ni, X. (2015). Longitudinal performance of spoken word perception in Mandarin pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology*, 79(10), 1677–1682.

Loundon, N., Marlin, S., Busquet, D., Denoyelle, F., Roger, G., Renaud, F., & Garabedian, E. N. (2003). Usher syndrome and cochlear implantation. *Otology & Neurotology, 24*, 216–221.

Lu, C. B., & Schuknecht, H. F. (1994). Pathology of prelingual profound deafness: Magnitude of labyrinthitis fibro-ossificans. *American Journal of Otology, 15*, 74–85.

Luce, P. A. (1986). *Neighborhoods of words in the mental lexicon. Research on speech perception*. Technical Report No. 6.

Luce, P. A, & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*, 1–36.

Luce, P., Pisoni, D., & Goldinger, S. (1990). *Similarity neighborhoods of spoken words. Cognitive models of speech processing: Psycholinguistic and computational perspectives* (pp. 122–147). Cambridge, MA: The MIT Press.

Markman, T. M., Quittner, A. L., Eisenberg, L. S., Tobey, E. A., Thal, D., Niparko, J. K., . . . The CDaCI Investigative Team. (2011). Language development after cochlear implantation: an epigenetic model. *Journal of Neurodevelopmental Disorders, 3*(4), 388–404.

Meinzen-Derr, J., Wiley, S., Creighton, J., Choo, D. (2007). Auditory skills checklist: Clinical tool for monitoring functional auditory skill development in young children with cochlear implants. *Annals of Otology Rhinology and Laryngology*, 116(11), 812–818.

Miyamoto, R. T., Colson, B., Henning, S., & Pisoni, D. (2017). Cochlear implantation in infants below 12 months of age. *World Journal of Otorhinolaryngology-Head and Neck Surgery*, *3*(4), 214–218.

Moeller, M. P. (2000). Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics, 106*, E43.

Moog, J. S., & Geers, A. (1990). *Early speech perception test for profoundly hearing-impaired children.* St. Louis, MO: Central Institute for the Deaf.

Moog, J. S., & Geers, A. E. (2010). Early educational placement and later language outcomes for children with cochlear implants. *Otology & Neurotology, 31*, 1315–1319.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Nadol, J. B. Jr., & Hsu, W. C. (1991). Histopathologic correlation of spiral ganglion cell count and new bone formation in the cochlea following meningogenic labyrinthitis and deafness. *Annals of Otology, Rhinology, and Laryngology*, *100*(9 Pt. 1), 712–716.

Nicholas, J. G. & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech-Language-Hearing Research, 50*(4), 1048–1062.

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N. Y., Quittner, A. L., Fink, N. E., & CDaCI Investigative Team. (2010). Spoken language development in children following cochlear implantation. *Journal of the American Medical Association*, 303(15), 1498–1506.

Nober, L. W., & Nober, E. H. (1975). Auditory discrimination of learning disabled children in quiet and classroom noise. *Journal of Learning Disabilities, 8*, 656–659.

Olsen, W. O. (1998). Average speech levels and spectra in various speaking/listening conditions: A summary of the Pearson, Bennett & Fidel Report (1977). *American Journal of Audiology, 7*, 21–25.

Palmer, C. V., & Mormer, E. (1999). Goals and expectations of the hearing aid fitting. *Trends in Amplification, 4*(2), 61–71.

Papsin, B. C. (2005). Cochlear implantation in children with anomalous cochleovestibular anatomy. *Laryngoscope*, 115(1 Pt. 2 Suppl. 106), 1–26.

Pearsons, K. S., Bennett, R. L., & Fidell, S. (1977). *Speech levels in various noise environments* (Report No. EPA600/1-77-025). Washington, DC: U.S. Environmental Protection Agency.

Peng, K. A., Kuan, E. C., Hagan, S., Wilkinson, E. P., & Miller, M. E. (2017). Cochlear nerve aplasia and hypoplasia: Predictors of cochlear implant success. *Otolaryngology-Head and Neck Surgery*, *157*(3), 392–400.

Peterson, G. E., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech and Hearing Disorders, 27*, 62–72.

Peterson, A., Shallop, J., Driscoll, C., Breneman, A., Babb, J., Stoeckel, R., & Fabry, L. (2003). Outcomes of cochlear implantation in children with auditory neuropathy. *Journal of the American Academy of Audiology, 14*, 188–201.

Phelan, E., Pal, R., Henderson, L., Green, K. M., & Bruce, I. A. (2016). The management of children with Down syndrome and profound hearing loss. *Cochlear Implants International*, *17*(1), 52–57.

Ponton, C. W., Eggermont, J. J., Don, M., Waring, M. D., Kwong, B., Cunningham, J., & Trautwein, P. (2000). Maturation of the mismatch negativity: Effects of profound deafness and cochlear implant use. *Audiology and Neurotology, 5*(3–4), 167–185.

Raine, C. H., Kurukulasuriva, M. F., Bajaj, Y., & Strachan, D. R. (2008). Cochlear implantation in Refsum's disease. *Cochlear Implants International, 9*, 97–102.

Rance, G., & Barker, E. J. (2008). Speech perception in children with auditory neuropathy/dyssynchrony managed with either hearing aids or cochlear implants. *Otology & Neurotology, 29*, 179–182.

Rance, G., Beer, D. E., Cone-Wesson, B., Shepherd, R. K., Dowell, R. C., King, A. M., . . . Clark, G. M. (1999). Clinical findings for a group of infants and young children with auditory neuropathy. *Ear and Hearing, 20*, 238–252.

Rehm, H. L. (2005). A genetic approach to the child with sensorineural hearing loss. *Seminars in Perinatology, 29*, 173–181.

Robbins, A. M., Renshaw, J. J., & Berry, S. W. (1991). Evaluating meaningful auditory integration in profoundly hearing-impaired children. *American Journal of Otology, 12*(Suppl.), 144–150.

Robbins, A. M., & Osberger, M. J. (1990). Meaningful use of speech scale (MUSS). Indianapolis, IN: Indiana University School of Medicine.

Roberts, C., & Hindley, P. (1999). Practitioner review: The assessment and treatment of deaf children with psychiatric disorders. *Journal of Child Psychology and Psychiatry, 40*(2), 151–167.

Roeser, R., & Clark, J. (2008). Live voice speech recognition audiometry: Stop the madness. *Audiology Today, 20*, 32–33.

Roizen, N. J., Wolters, C., Nicol, T., & Blondis, T. A. (1993). Hearing loss in children with Down syndrome. *Journal of Pediatrics, 123*, S9–S12.

Rossi, K. (2003). *Talk around the clock.* Washington, DC: The Alexander Graham Bell Association for Deaf and Hard of Hearing.

Sanders, D. (1965). Noise conditions in normal school classrooms. *Exceptional Child, 31*, 344–353.

Schaefer, S. M., de Kruijf, M., Henderson, L., Metryka, A., O'Driscoll, M., & Bruce, I. A. (2019). Improved speech and language development after unilateral cochlear implantation in children with a potentially useable contralateral ear. *Cochlear Implants International, 20*(1), 39–46.

Scollie, S., Seewald, R., Cornelisse, L., Moodie, S., Bagatto, M., Laurnagaray, D., . . . Pumford, J. (2005). The desired sensation level multistage input/output algorithm. *Trends in Amplification, 9*(4), 159–197.

Seewald, R. C., Ross, M., & Spiro, M. K. (1985). Selecting amplification characteristics for young hearing impaired children. *Ear and Hearing, 6*, 48–51.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Seymour, F. K., Cruise, A., Lavy, J. A., Bradley, J., Beale, T., Graham, J. M., & Saeed, S. R. (2010). Cognenital profound hearing loss: Management of hypoplastic and aplastic vestibulocochlear nerves. *Cochlear Implants International, 11*(Suppl. 1), 213–216.

Shallop, J. K., Peterson, A., Facer, G. W., Fabry, L. B., & Driscoll, C. L. W. (2001). Cochlear implants in five cases of auditory neuropathy: Postoperative findings and progress. *Laryngoscope, 111*, 555–562.

Sharma, A., Dorman, M., Spahr, A., & Todd, N. W. (2002). Early cochlear implantation in children allows normal development of central auditory pathways. *Annals of Otology, Rhinology & Laryngology Supplement*, 189, 38–41.

Sharma, A., & Dorman, M. F. (2006). Central auditory development in children with cochlear implants: Clinical implications. *Advances in Otorhinolaryngology, 64*, 66–88.

Sharma, A., Nash, A. A., & Dorman, M. (2009). Cortical development, plasticity and re-organization in children with cochlear implants. *Journal of Communication Disorders, 42*(4), 272–279.

Smeds, K., Wolters, F., & Rung, M. (2015). Estimation of signal-to-noise ratios in realistic sound scenarios. *Journal of the American Academy of Audiology*, *26*(2), 183–196. https://doi.org/10.3766/jaaa.26.2.7

Smith, J. H., Bale, J. F., & White, K. R. (2005). Sensorineural hearing loss in children. *Lancet, 365*, 879–890.

Spahr, A. J., Dorman, M. F., Litvak, L. M., Cook, S. J., Loiselle, L. M., Dejong, M. D., . . . Gifford, R. H. (2014). Development and validation of the pediatric AzBio sentence lists. *Ear and Hearing*, *35*(4), 418–422. https://doi.org/10.1097/AUD.0000000000000031

Stovall, D. (1982). *Teaching speech to hearing impaired infants and children.* Springfield, IL: Charles C. Thomas.

Stredler-Brown, A., & DeConde Johnson, C. (2003). *Functional auditory performance indicators: An integrated approach to auditory development.* Colorado Department of Education, Special Education Services Unit. Retrieved from http://www.cde.state.co.us/cdesped/SpecificDisability-Hearing.html

Spitzer, J. B., & Zavala, J. S. (2011). Development of Spanish version of the Littlears Parental Questionnaire for use in the United States and Latin America. *Audiology Research*, *1*(2), 23–29.

Szagun, G., & Stumper, B. (2012). Age or experience? The influence of age at implantation, social and linguistic environment on language development in children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 55*(6), 1640–1654.

Tajudeen, B. A., Waltzman, S. B., Jethanamest, D., & Svirsky, M. A. (2010). Speech perception in congenitally deaf children receiving cochlear implants in the first year of life. *Otology & Neurotology*, *31*(8), 1254–1260.

Teagle, H. F. B., Rousch, P. A., Woodard, J. S., Hatch, D. R., Zdanski, C. J., Buss, E., & Buchman, C. A. (2010). Cochlear implantation in children with auditory neuropathy spectrum disorder. *Ear and Hearing, 31*, 325–335.

Tobey, E. A., Shin, S., Sundarrajan, M., & Geers, A. E. (2011). Spoken word recognition in adolescent cochlear implant users during quiet and multispeaker babble conditions. *Otology & Neurotology, 32*(3), 413–418.

Tobey, E. A., Thal, D., Niparko, J. K., Eisenberg, L. S., Quittner, A. L., & Wang, N. Y., & CDaCI Investigative Team. (2013). Influence of implantation age on school-age language performance in pediatric cochlear implant users. *International Journal of Audiology*, *52*(4), 219–229.

Tomblin, J. B., Barker, B. A., Spencer, L. J., Zhang, X., & Gantz, B. J. (2005). The effect of age at cochlear implant initial stimulation on expressive language growth in infants and toddlers. *Journal of Speech, Language and Hearing Research*, *48*(4), 853–867.

Uhler, K. M., Baca, R., Dudas, E., & Fredrickson, T. (2015). Refining stimulus parameters in assessing infant speech perception using visual reinforcement infant speech discrimination: Sensation level. *Journal of the American Academy of Audiology*, *26*(10), 807–814.

Uhler, K., Biever, A., & Gifford, R. H. (2016). Method of speech stimulus presentation impacts pediatric speech recognition: Monitored live voice versus recorded speech. *Otology & Neurotology, 37*(2), e70–74.

Uhler, K. M., Gifford, R. H., Forsteer, J. E., Anderson, M., Tierney, E., Claycomb, S. D., & Werner, L. A. (2018). Refining stimulus parameters in assessing infant speech perception using visual reinforcement infant speech discrimination in infants with and without hearing loss: Presentation level. *Journal of the American Academy of Audiology, 29*(9), 847–854.

Uhler, K., Yoshinaga-Itano C., Gabbard S. A., Rothpletz, A.M., & Jenkins, H. (2011). Longitudinal infant speech perception in young cochlear implant users. *Journal of the American Academy of Audiology, 22*(3), 129–142.

Uhler, K., Warner-Czyz A., & Gifford, R., & Pediatric working group. (2017). Pediatric Minimum Speech Test Battery. *Journal of the American Academy of Audiology, 28*(3), 232–247.

Van Naarden, K., Decoufle, P., & Caldwell, K. (1999). Prevalence and characteristics of children with serious hearing impairment in metropolitan Atlanta, 1991–1993. *Pediatrics*, *103*(3), 570–575.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

van Wieringen, A., & Wouters, J. (1999). Natural vowel and consonant recognition by Laura Cochlear implantees. *Ear and Hearing*, *20*, 89–103.

Vescan, A., Parnes, L. S., Cucci, R. A., Smith, R. J., & MacNeill, C. (2002). Cochlear implantation and Pendred's syndrome mutation in monozygotic twins with large vestibular aqueduct syndrome. *Journal of Otolaryngology, 31*, 54–57.

Vesseur, A., Free, R., Snels, C., Dekker, F., Mylanus, E., Verbist, B., & Frijns, J. (2018). Hearing restoration in cochlear nerve deficiency: The choice between cochlear implant or auditory brainstem implant, a meta-analysis. *Otology & Neurotology*, *39*(4), 428–437.

Vincenti, V., Ormitti, F., Ventura, E., Guida, M., Piccinini, A., & Pasanisi, E. (2014). Cochlear implantation in children with cochlear nerve deficiency. *International Journal of Pediatric Otorhinolaryngology, 78*(6), 912–917.

Weichbold, V., Tsiakpini, L., Coninx, F., & D'Haese, P. (2005). Development of a parent questionnaire for assessment of auditory behaviour of infants up to two years of age. *Laryngorhinootologie, 84*(5), 328–334.

White, K. R., Vohr, B. R., Meyer, S., Widen, J. E., Johnson, J. L., Gravel, J. S., . . . Weirather, Y. (2005). A multisite study to examine the efficacy of the Otoacoustic Emission/ Automated Auditory Brainstem Response Newborn Hearing Screening Protocol: Research design and results of the study. *American Journal of Audiology, 14*, S186–S199.

Zhang, Z., Li, Y., Hu, L., Wang, Z., Huang, Q., & Wu, H. (2012). Cochlear implantation in children with cochlear nerve deficiency: A report of nine cases. *International Journal of Pediatric Otorhinolaryngology*, *76*(8), 1188–1195.

Zimmerman-Phillips, S., Robbins, A. M., & Osberger, M. J. (2000). Assessing cochlear implant benefit in very young children. *Annals of Otology, Rhinology, and Laryngology Supplement, 185*, 42–43.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

4

Role of the Speech-Language Pathologist in the Assessment of Pediatric Cochlear Implant Candidacy

Emily Lund

INTRODUCTION

In the preoperative cochlear implant candidacy process, teams must consider the ways hearing loss has affected a child's development; therefore, team members, apart from the audiologist and surgeon, play a crucial role in determining cochlear implant candidacy. Speech-language pathologists (SLPs), for example, have training necessary to assess a child's speech, language, and academic skills (American Speech-Language-Hearing Association, 2001). Assessments from SLPs can provide information about a candidate's current level of functioning and rate of development. Furthermore, the SLP may help provide insight into expected outcomes for a child once he or she has a cochlear implant; thus, information from an SLP can help a team make an informed decision about a child's candidacy and provide possible expectations for a child post-implant.

Many assessments are available to measure a child's communication skills. To effectively administer and interpret those assessments, professionals must understand the purpose of the instrument and the skills it actually measures. This chapter provides a description of general principles of standardized assessment, along with descriptions of specific evaluation tools and metrics that are widely used by SLPs working with children with hearing loss. In addition, this chapter discusses evaluation and therapy schedules necessary for children with hearing loss prior to cochlear implantation.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

PRINCIPLES OF STANDARDIZED EVALUATION

SLPs often use standardized assessments for evaluations. Standardized assessments are designed to be administered in the same way to all children.

Generally, standardized assessments can be divided into two categories: norm-referenced assessments and criterion-referenced assessments. These types of assessments can serve very different purposes. A norm-referenced assessment instrument is designed to determine if a child's skills (speech, language, etc.) are delayed compared with a sample of his or her peers. Essentially, these assessments serve to answer the question: Is a child delayed, or is he or she functioning within the range of normal (McCauley & Swisher, 1984)? To answer this question, norm-referenced tests assess broad skill sets. Criterion-referenced assessments, on the other hand, help to answer the question: Is a child able to perform a given skill/task to a certain criterion level? The criterion-referenced assessment does not compare a child with his or her peers but rather is based on the theory that a child should have mastered a set of skills by a given age, and assesses the child's mastery of those skills (Swaminathan, Hambleton, & Algina, 1974). Criterion-referenced tests tend to assess specific skill sets. Understanding the difference between information derived from a norm-referenced versus criterion-referenced assessment is critical for interpretation of results.

Norm-Referenced Assessments

Norm-referenced assessments are designed to identify delayed skill sets, not to capture change over short periods of time. Specific items on norm-referenced assessments are included as a part of the instrument because they reliably distinguish between delayed versus typically developing children. These items are not thought to be representative of a child's performance across the entire range of a given skill. For example, the Clinical Evaluation of Language Fundamentals (fifth edition) assessment "Sentence Comprehension" subtest has an item requiring children to "point to [the picture that shows] the boy who is sitting under the big tree is eating a banana (Wiig, Semel, & Secord, 2013)." A child's inability to complete this task does not indicate that he or she does not understand concept words like "under" or how to follow directions, nor does it indicate that a child who can answer this question has adequate sentence comprehension skills. Rather, this item was chosen because, in combination with the other items on this instrument, performance on the item reliably separates children who do and do not have typical sentence comprehension skills; thus, performance on individual items from a norm-referenced assessment should not be used to discuss individual skill sets of a child, but only to talk broadly about whether a child is delayed or not.

Criterion-Referenced Assessments

Criterion-referenced assessments are designed to measure mastery of certain skill sets without reference to the performance of other children (Popham & Husek, 1969). These assessments often contain items ordered by level of difficulty. A child's performance on a criterion-referenced item or group of items should indicate mastery of a set of skills (Popham & Husek, 1969). For example, the PALS-PreK Letter Naming subtest requires children to identify the names of letters of the alphabet (Invernizzi, Sullivan, Meier, & Swank, 2004). If a child is unable to name specific letters, an examiner can conclude that the child's performance is indicative of his or her letter-naming skills. Because criterion-referenced assessments are designed to capture a child's mastery of a skill, they can be used to monitor progress.

Why must an SLP understand the difference between norm-referenced and criterion-referenced standardized measures? In reporting information back to a cochlear implant candidacy team, the SLP must be able to accurately interpret his or her findings. A norm-referenced measure can tell the team whether or not a child is experiencing delays, and in which domains, as compared to children with normal hearing of the same age. A criterion-referenced measure, on the other hand, can identify more specific skills that are delayed and may be useful for tracking postimplant progress.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

ASSESSING CHILDREN WITH HEARING LOSS

An SLP involved in the cochlear implant candidacy process is charged with determining a

child's current level of communicative functioning and potential outcomes postimplantation; thus, the SLP needs to be able to analyze a specific assessment's validity for measuring the skills of an individual child with hearing loss. Central to this task lays the question: Does the instrument capture a child's skill proficiency or ability? Proficiency is a child's skill level in comparison to a fluent adult model (Bachman & Savignon, 2002). Ability, on the other hand, is a child's capacity or potential to acquire skills (McNamara, 1995). This distinction between proficiency and ability in children with hearing loss is an important one during assessment interpretation, and subsequently for cochlear implant candidacy decisions and counseling.

Proficiency can be impacted by a child's environment; he or she may not display certain behaviors due to lack of opportunities to learn, not lack of ability. In addition to a child not being able to perform a skill because of his or her hearing status, the proficiency of the child may be also impacted by factors such as the socioeconomic status of his or her home environment. The ability to label objects, for example, may be impacted by a child's actual knowledge of the name of that object but may also be influenced by his or her family's experience with naming objects or with those specific objects at home (Lidz & Pena, 1996). Some cultures do not regularly label objects. Consequently, in a testing situation a child's deficient object labeling may not be representative of a lack of skill but rather reduced procedure familiarity.

A child's environment should not impact his or her innate ability or inability to acquire a skill (McNamara, 1995). For example, a child who lacks the ability to use the social rules of language may not be able to do so even when environmental factors (i.e., lack of familiarity with procedure) are improved; thus, a child's abilities may be predictive of his or her performance following implantation. Unfortunately, ability separate from environmental influence is difficult to measure (McNamara, 1995). Proficiency, change over time, and learning tasks are often used as indicators of a child's underlying ability (Lidz & Pena, 1996).

SLPs who work with children with hearing loss should have an understanding of specific assessments and whether they tap a child's ability or proficiency. Many assessments used with children, norm referenced or criterion referenced, were not specifically designed to address the needs of children with hearing loss. As a result, professionals who administer and interpret standardized assessments for children with hearing loss should be able to analyze the actual skills measured by the instrument. For example, many standardized assessments do not allow the examiner to repeat items to a child; thus, a child with hearing loss may miss an item measuring a language skill not because the child lacks that skill, but because he or she did not hear the question the first time. In this case, the assessment is not measuring a child's real language proficiency, but rather his or her ability to hear the question. This instrument, therefore, may be representative of a child's question-answering proficiency in a testing environment, but not his or her language proficiency or ability (i.e., answering questions within daily activities). For every assessment tool used to evaluate a child with hearing loss, a professional must consider the skill actually being assessed in relation to the conclusions he or she draws.

In the following sections, specific common assessment instruments for children with hearing loss are described to assist professionals in determining the utility of information presented for implant candidacy.

Specific Assessments

Assessments of Speech Production

Assessments of speech production, or articulation, are used to evaluate a child's phonological development, a key domain of oral language (see Table 4–1). The measures used to describe speech production vary by age of the child being evaluated. During infancy, patterns of speech production are observable and predictable even before children begin to use language. Vocalization and babble can provide valuable information about a child's articulatory development and possibly present red flags for delayed development (Robbins, 2005). Children with hearing loss have delayed early babbling behaviors, which may function as a precursor to their later speech delays (Moeller et al., 2007).

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 4–1. Speech Production Assessment Instrument Reference Chart

Measure Name	Type of Measure	Domains Assessed	Age Range	Information Collected
Rosetti Infant Toddler Language Scales (RI-TLS)	Criterion-Referenced	*Subtests*: Interaction-Attachment, Pragmatics, Gesture, Play, Language Comprehension, Language Expression	0 to 36 months	Direct Observation, Behavior Elicitation, Parent Report
Cottage Acquisition Scales for Listening, Language and Speech-Second Edition (CASSLS)	Criterion-Referenced	*Forms available*: Preverbal, PreSentence, Simple-Sentence, Complex Sentence, Sounds and Speech	0 to 8 years	Direct Observation, Behavior Elicitation, Parent Report
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition	Criterion-Referenced	Audition, Speech, Cognition, Social Interaction, Fine Motor Skills, Gross Motor Skills	0 to 6 years	Direct Observation, Behavior Elicitation, Parent Report
Goldman-Fristoe Test of Articulation-3 (GFTA-3)	Norm-Referenced	Articulation	2 to 21 years	Behavior Elicitation
Khan-Lewis Phonological Analysis- Third Edition (KLPA-3)	Criterion-Referenced (to be used in combination with GFTA-3)	Phonological Processes (Articulation)	2 to 21 years	Behavior Elicitation
Arizona Articulation Proficiency Scale- Fourth Edition (AAPS-4)	Norm-Referenced	Articulation	1.5 to 18 years	Behavior Elicitation

Accordingly, careful characterization of a child's speech skills serves to demonstrate that a child is or is not developing appropriate precursor skills to good speech patterns, an important consideration in the cochlear implant candidacy process.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Because examiners cannot directly elicit infant speech patterns, most evaluation data during infancy come from direct observation and parental reports. Many SLPs use articulation inventories or lists of phonemes a child may produce (standardized or not) to determine whether a child's vocalizations are developing at an expected rate. For example, SLPs know that children who are typically developing are expected to produce canonical babble by the age of 10 months (Oller & Eilers, 1988). This benchmark may serve as an indicator to a professional that an infant's speech is or is not developing at the expected rate; however, speech patterns this early in development are broadly variable and should be interpreted as such.

Criterion-referenced checklists that evaluate speech production, along with several domains of behavior, can be useful for children with hearing loss. Many developmental scales use the principles of criterion-referenced instruments. The Rosetti Infant–Toddler Language Scale (RI-TLS) (Rossetti, 1990) is one example of a developmental scale used to measure language development, including speech production. This instrument requires an examiner to observe and elicit behavior, as well as solicit parental reports to determine whether a

child possesses age-appropriate communicative skills. Behaviors on this scale are divided into the following domains: interaction-attachment, pragmatics, gesture, play, language comprehension, and language expression. Mastery within a domain is established when a child displays all of the behaviors within a given age range (e.g., 21 to 24 months); thus, delays are calculated as a percentage of a child's chronologic age. For example, a child with skills at 9 to 12 months who is 18 months old displays a 33% delay according to the RI-TLS.

Criterion-referenced instruments measuring multiple domains can help a cochlear implant team determine whether a child's speech-production development is consistent with his or her other skills. For example, a child with no delay in play skills but a 33% delay in speech-production skills clearly has a language-specific delay not predicted by his or her other skill proficiency. This result indicates that the access to sound that a child has is not sufficient for normal receptive language development. Other instruments used in a similar fashion to evaluate the speech production of infants and toddlers with hearing loss include the Cottage Acquisition Scales for Listening, Language and Speech (Wilkes, 2001) and St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition (Tuohy, Brown, & Mercer-Moseley, 2005).

Speech-production patterns of typical preschool children are also highly variable. Articulation errors are still common at this age; however, patterns of error remain fairly predictable, and a child's errors that fall outside of these patterns (atypical errors) are less likely to correct naturally over time (Ohde & Sharf, 1992). A thorough evaluation of a preschool child's articulation and consequent intelligibility can provide a cochlear implant team with important information about a child's speech perception and possibly continued development (Eisenberg, 2007).

Speech-language pathologists have a broader range of instruments to choose from for preschool and school-age children because these children are able to produce and imitate words and sentences. The Goldman-Fristoe Test of Articulation-3 (GFTA-3), for example, is a norm-referenced test that requires children to produce single words in isolation or in sentences (preferably spontaneously) (Goldman & Fristoe, 2015). Each consonant in the English language is produced in word-initial, word-medial, and word-final positions. The number of errors tells an SLP whether or not the child's general articulation skills are age appropriate. As with other norm-referenced assessments, this instrument describes whether a child's articulation proficiency is within the range of normal for his or her age.

The GFTA-3 can be used in conjunction with the Khan-Lewis Phonological Analysis (KLPA-3) to describe a child's production error patterns (Khan & Lewis, 2015). This instrument identifies error patterns (i.e., backing, final-consonant deletion) based on a child's performance on the GFTA-3. Together, data from these instruments can be valuable to a cochlear implant team in determining whether a child's articulation is age appropriate and whether a child's patterns of articulation appear typical or atypical. In other words, a child who does not appear to have typical patterns of articulation may be a candidate for a cochlear implant because he or she is not developing speech-production skills appropriately.

The Arizona Articulation Proficiency Scale (AAPS-4) is another widely used, norm-referenced articulation assessment (Fudala & Stengall, 2017). Like the GFTA-3, the AAPS-4 requires children to produce single words to label pictures. The AAPS-4 measures both consonant and vowel production; however, it does not measure each of the English consonants in different word-placement positions. Vowels are among the earliest produced sounds by children, and most children master vowel sounds before they master consonant sound production (Ohde & Sharf, 1992). Children with hearing loss, on the contrary, frequently display prolonged difficulty producing correct and consistent vowel sounds (Eisenberg, 2007). Consequently, the AAPS can provide valuable information to a cochlear implant team about a child's proficiency producing vowel sounds.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Assessments of Language

Language assessments can evaluate many domains of children's development, including vocabulary, grammar, and pragmatics. Prior to implantation, a team should have an understanding

of how hearing loss has affected that child's ability to develop language. Many criterion-referenced and norm-referenced assessments are available to SLPs to evaluate both early and late stages of language development. Several common assessments of each type are described below. These descriptions, however, are not all encompassing; many additional assessments of language exist.

As with assessments of speech production, language assessments used with infants are primarily criterion referenced and based on parental reports or direct observation. One common criterion-referenced assessment of infant and toddler vocabulary is the MacArthur-Bates Communicative Development Inventory (Fenson et al., 2006). This instrument is based on parental reports; parents are asked to identify words, gestures, and phrases from daily life that a child is able to understand or produce. Instruments such as the CDI are useful for evaluating patterns of vocabulary knowledge and comparing a child's total number of vocabulary words to the number of words expected for his or her age. This information can demonstrate to a cochlear implant team that a child is or is not developing early vocabulary at an expected rate.

Common norm-referenced assessments of expressive and receptive vocabulary include the Peabody Picture Vocabulary Test (PPVT-5), The Expressive Vocabulary Test (EVT-3), the Receptive One Word Picture Vocabulary Test (ROWPVT-4), and the Expressive One Word Picture Vocabulary Test (EOWPVT-4) (Dunn, 2019; Martin & Brownell, 2010a, 2010b; Williams, 2007). Receptive assessments (PPVT-5 and ROWPVT-4) require children to point to one of four pictures best represented by the examiner's label, whereas expressive assessments (EVT-3 and EOWPVT-4) require children to label a picture or group of pictures. A raw score is derived based on the number of correctly labeled or identified pictures and then compared with the scores of a child's same-age peers. These instruments are useful for determining whether or not a child has delayed vocabulary skills; however, these types of assessments do not describe a child's depth of vocabulary knowledge, nor do they represent patterns of knowledge (i.e., knows many individual labels but not superordinate category labels).

Many SLPs choose to use omnibus assessments of language development, especially as children begin to acquire grammar. Norm-referenced assessments for preschool-aged children include the Clinical Evaluation of Language Fundamentals (preschoovl edition), the New Reynell Developmental Language Scales, and the Preschool Language Scale (fifth edition), as well as many others (Edward, Letts, & Sinka, 2011; Semel, Wiig, & Secord, 2004; Zimmerman, Steiner, & Pond, 2010). These instruments assess a variety of domains (Table 4–2), requiring children to complete tasks such as following directions, identifying pictures, completing sentences, and answering questions. These instruments then yield subtest and total language scores that a professional can compare with those of children of that child's same age. As with other norm-referenced assessments, these instruments do not reveal patterns of language errors because they only sample a few specific behaviors. Subtest scores, in fact, should be interpreted carefully; individual subtests may not share the overall sensitivity and specificity characteristics of a given instrument (Plante & Vance, 1995). Data from these assessments, however, can demonstrate to a cochlear implant team that a child has not developed language skills consistent with age expectations.

Some SLPs may also choose to administer criterion-referenced, omnibus assessments of language. The RI-TLS, for example, yields information about receptive and expressive language development. Many SLPs who work with children with hearing loss use scales specifically designed for children with hearing loss. For example, the Cottage Acquisition Scales for Listening, Language, and Speech (Wilkes, 2001) include checklists of skills within various domains, including listening comprehension, vocabulary, and grammatical development. Checklists represent various levels of language development, including pre-verbal, pre-sentence, simple sentence, and complex sentence levels. Similarly, the SKI-HI Language Development Scale (second edition; Watkins, 2004) provides parent and professional checklists of developmentally ordered receptive and expressive language skills. SLPs can determine, based on structured observation, whether or not a child has mastered those skills expected for his or her

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 4–2. Language Assessment Instrument Reference Chart

Measure Name	*Type of Measure*	*Domains Assessed*	*Age Range*	*Information Collected*
MacArthur-Bates Communicative Development Inventory (CDI)	Criterion-Referenced	*Forms*: Words and Gestures, Words and Sentences	8 to 30 months	Direct Observation Parent Report
Peabody Picture Vocabulary Test- Fifth Edition (PPVT-5)	Norm-Referenced	Receptive Vocabulary	2.5 to 90 years	Behavior Elicitation
Receptive One Word Picture Vocabulary Test- Fourth Edition (ROWPVT-4)	Norm-Referenced	Receptive Vocabulary	2 to 18 years	Behavior Elicitation
Expressive Vocabulary Test- Third Edition (EVT-3)	Norm-Referenced	Expressive Vocabulary	2.5 to 90 years	Behavior Elicitation
Expressive One Word Picture Vocabulary Test (EOWPVT-4)	Norm-Referenced	Expressive Vocabulary	2 to 18 years	Behavior Elicitation
Clinical Evaluation of Language Fundamentals-Preschool Edition (CELF-P2)	Norm-Referenced	*Composite Scores*: Core Language, Receptive Language, Expressive Language, Language Content, Language Structure	3 to 6 years	Behavior Elicitation
New Reynell Developmental Language Scales (RDLS)	Norm-Referenced	Receptive Language, Expressive Language	1 to 6 years	Behavior Elicitation
Preschool Language Scale- Fifth Edition (PLS-5)	Norm-referenced	*Subtests*: Auditory Comprehension, Expressive Language	0 to 6 years	Direct Observation, Behavior Elicitation, Parent Report
Rosetti Infant Toddler Language Scales (RI-TLS)	Criterion-Referenced	*Subtests*: Interaction-Attachment, Pragmatics, Gesture, Play, Language Comprehension, Language Expression	0 to 36 months	Direct Observation, Behavior Elicitation, Parent Report
Cottage Acquisition Scales for Listening, Language and Speech (CASSLS)	Criterion-Referenced	*Forms available*: Preverbal, Presentence, Simple-Sentence, Complex Sentence, Sounds and Speech	0 to 8 years	Direct Observation, Behavior Elicitation, Parent Report

continues

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 4–2. *continued*

Measure Name	Type of Measure	Domains Assessed	Age Range	Information Collected
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition	Criterion-Referenced	Audition, Speech, Cognition, Social Interaction, Fine Motor Skills, Gross Motor Skills	0 to 6 years	Direct Observation, Behavior Elicitation, Parent Report
SKI-HI Language Development Scale-Second Edition	Criterion-Referenced	Receptive Language, Expressive Language	0 to 5 years	Parent Report
Clinical Evaluation of Language Fundamentals-Fifth Edition (CELF-5)	Norm-Referenced	*Composite Scores*: Core Language, Receptive Language, Expressive Language, Language Content, Language Structure	5 to 21 years	Behavior Elicitation
Oral and Written Language Scales (OWLS)	Norm-Referenced	*Scales*: Listening Comprehension, Oral Expression, Written Expression	3 to 21 years	Behavior Elicitation
Comprehensive Assessment of Spoken Language (CASL-2)	Norm-Referenced	Receptive Language, Expressive Language	3 to 21 years	Behavior Elicitation
Test of Pragmatic Language- Second Edition (TOPL-2)	Norm-Referenced	Pragmatic Language	6 to 18 years	Behavior Elicitation
Test of Auditory Comprehension of Language- Fourth Edition (TACL-4)	Norm-Referenced	Receptive Language	3 to 9 years	Behavior Elicitation
The Word Test: Adolescents	Norm-Referenced	Vocabulary	12+ years	Behavior Elicitation
The Word Test: Elementary	Norm-Referenced	Vocabulary	6 to 11 years	Behavior Elicitation

STUDENTS-HUB.com Uploaded By: tuka abuzneid

age. An advantage of these instruments is that they provide detailed examinations of specific language skills.

Assessments available to school-age children often assess higher-level language skills, such as making inferences or explaining word meanings. Information taken from these assessment instruments may be useful to cochlear implant teams evaluating the candidacy of an older child, such as one with a progressive loss. Some omnibus, norm-referenced language assessments for school-age children include the Clinical Evaluation of Language Fundamentals- Fifth Edition (Wiig, Semel & Secord, 2013), the Oral and Written Language Scales (second edition; Carrow-Woolfolk, 1995) and the Comprehensive Assessment of Spoken

Language—Second Edition (see Table 4–2) (Carrow-Woolfolk, 2017). These assessments require children to use their language skills to complete tasks such as comprehending paragraphs, following directions, and generating sentences. These instruments, like other norm-referenced assessments, yield general standard scores to compare a child's language skills with those of other children of the same age.

Because language deficits of school-age children may be subtle or limited to a certain language domain, many assessments target more specific language skills. The Test of Pragmatic Language (second edition) (Phelps-Terasaki & Phelps-Gunn, 2007), for example, rather than testing grammar or vocabulary knowledge, specifically assesses a child's ability to use language socially. The Test of Auditory Comprehension of Language (fourth edition) (Carrow-Woolfolk, 2014) assesses auditory comprehension skills but not expressive language. The Word Test-3 (Bowers, Huisingh, LoGiudice, & Orman, 2014) taps semantic knowledge and organization by requiring children, for example, to name categories, generate synonyms, and name category members. Each of these instruments can provide information about deficits related to hearing loss that cause a child to continue to struggle academically. Such information is valuable to the cochlear implant team as they consider barriers to achieving language-skill proficiency.

Assessments of Auditory Skills

Evaluation of a child's candidacy for a cochlear implant should include assessments of his or her use of limited auditory skills in real-world situations (Table 4–3). An SLP can observe and assess the auditory behaviors of children over the course of a few visits. Auditory assessments can help a team determine whether a child's auditory behaviors are consistent with his or her responses to speech sounds in the audiology booth.

The Early Speech Perception Test (ESP) (Moog & Geers, 1990) is a criterion-referenced assessment instrument used by professionals to evaluate a child's ability to discriminate different types of sounds. A child is asked to differentiate between sounds of differing gross durations ("aaa" versus "hop hop hop"), between words of differing duration ("birthday cake" versus "bird"), and between words of the same duration with different phonemes ("bed" versus "book"). Young children can choose toys to match target words, and older children

Table 4–3. Auditory Functioning Assessment Instrument Reference Chart

Measure Name	*Type of Measure*	*Domains Assessed*	*Age Range*	*Information Collected*
Early Speech Perception Test (ESP)	Criterion-Referenced	Auditory Discrimination and Identification	3 to12 years	Behavior Elicitation
Auditory Perception Test for the Hearing Impaired-Third Edition (APT/HI-3)	Criterion-Referenced	Auditory Discrimination and Identification	5+ years	Behavior Elicitation
Cottage Acquisition Scales for Listening, Language and Speech (CASSLS)	Criterion-Referenced	*Forms available*: Pre-Verbal, Pre-Sentence, Simple-Sentence, Complex Sentence, Sounds and Speech	0 to 8 years	Direct Observation, Behavior Elicitation, Parent Report
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition	Criterion-Referenced	Audition, Speech, Cognition, Social Interaction, Fine Motor Skills, Gross Motor Skills	0 to 6 years	Direct Observation, Behavior Elicitation, Parent Report

STUDENTSHUB.com Uploaded By: tuka abuzneid

can point to pictures to demonstrate their discrimination skills. Benchmarks set by the authors (e.g., 8 of 12 correct responses) help professionals to determine whether a child has mastered the different levels of auditory discrimination.

The Auditory Perception Test for the Hearing Impaired, Third Edition (APT/HI-3) (Allen, 2015) is another criterion-referenced instrument appropriate for school-age children. This instrument requires children to complete a series of receptive tasks of varying difficulty, including discriminating between sounds differing in suprasegmental features, between words with differing syllable numbers or consonants, and between sentences containing different words. The demands of this instrument (pointing to pictures in a booklet) are similar to the demands of other standardized tasks children are asked to complete; thus, a child's performance on the APT/HI-3 or the ESP may help an SLP to determine whether a child performs poorly on these instruments due limited auditory skills, limited language proficiency, or a combination of the two.

The measurement of functional auditory responses is difficult to separate from measurement of vocabulary and language knowledge. Consequently, results from either of these instruments should be interpreted with caution. Both instruments require children to recognize that spoken words can be consistently paired with objects or pictures, and to recall which spoken words are paired with any given set of objects. For example, a child may be able to discriminate between a one-syllable word and a three-syllable word, but he or she may demonstrate difficulty selecting "bird" versus "ice cream cone." Errors on either the ESP or the APT/HI-R could be influenced by lack of vocabulary knowledge rather than auditory skills. The interpretation of these instruments should therefore be combined with parent and clinician observation to determine how a child uses audition in his or her daily life. It may be that higher levels of auditory skill cannot be artificially separated from language knowledge.

Assessments of Academic Skills

Children who are candidates for cochlear implants after entering preschool have often been exposed to academic skills, most of which are language based. A thorough analysis of a child's communicative proficiency prior to receiving a cochlear implant, therefore, should include an assessment of his or her academic knowledge. An evaluation of a child's mastery of these skills can provide information about a child's ability to learn in a classroom setting.

Reading and writing are academic skills that are closely linked to language proficiency. Assessments of early literacy skills can predict later reading and writing achievement (Storch & Whitehurst, 2002). Because literacy outcomes of children with hearing loss are notoriously poor, cochlear implant teams may want to consider the impact of hearing loss on a child's early literacy abilities. Two norm-referenced assessments of early literacy skills are the Test of Preschool Early Literacy (TOPEL) (Lonigan, Wagner, & Torgesen, 2007) and the Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 1999). These assessments measure skills related to later literacy achievement, such as phonological awareness, phonological working memory, letter-sound identification, and print awareness. These instruments yield scores that allow professionals to compare a child to his or her same-age peers.

Many criterion-referenced assessments of literacy skills are also available. The Phonological Awareness Literacy Screening assessments (Pre-K, K, and 1, 2, 3) (Invernizzi, Meier, Swank, & Juel, 2004) are useful measures of literacy skills that include phonological awareness, print awareness, and early decoding abilities. These instruments evaluate a child's ability to complete literacy-related tasks. For example, if a child entering kindergarten should be able to identify sounds corresponding to letters, the PALS-Pre-K letter-sound subtest could be administered to see which sounds a child knows and does not know. The results of this kind of measure demonstrate to a cochlear implant team whether a child has been able to acquire the knowledge necessary to continue achieving academically.

Other assessments of academic concept knowledge include the Boehm Test of Basic Concepts (third edition) (BTBC) (Boehm, 2000) and the Bracken School Readiness Assessment (third edition) (BSRA; Bracken, 2007). The BTBC requires

STUDENTS-HUB.com Uploaded By: tuka abuzneid

children to show knowledge of concepts (such as "missing" or "below") by pointing to parts of pictures. The results of this assessment, however, should be interpreted with caution for children with hearing loss. Picture representations of these concepts often highlight the correct response within the picture. For example, the picture for the target "different" shows one different picture among several identical other pictures. Children with hearing loss may consistently display understanding of the concept by responding to salient pictured cues (one "different" picture among many that are the same) rather than responding to a known vocabulary word (comprehension of the word "different"). The BSRA assesses content knowledge of colors, letters, numbers, sizes, and shapes based on receptive and expressive responses. Both assessments can be used effectively to measure the academic concept knowledge of young children with hearing loss.

Older children often participate in formal academic assessment, and results from these assessments can also be useful to a cochlear implant team. Norm-referenced assessments of reading and other academic concepts, such as the Woodcock Reading Mastery Test (third edition) (Woodcock, 2011) or the Woodcock Johnson Test of Achievement – III (Woodcock, McGrew, & Mather, 2001), allow teams to compare a child's performance with that of other children of his or her age. Both instruments contain several subtests (Table 4–4), allowing professionals to evaluate a child's performance across several academic domains. Information from these instruments indicates to a team whether a child is performing academically at the level expected of his or her same-grade/age peers with normal hearing.

General education teachers and teachers of the deaf who interact regularly with students also can provide valuable insight to a cochlear implant team. Teachers often set benchmarks and use criterion-referenced assessments to monitor progress. As a result, classroom teachers of older children can provide important perspectives: a child's rate of academic growth may indicate that he or she is able or unable to keep up with work presented to children of his or her same grade. The Screening Instrument for Targeting Educational Risk (SIFTER) is a rating scale teachers can use to compare a child's academics, attention, communication, classroom participation, and school behavior to those of other children in the classroom (Anderson, 1989). The cochlear implant team can use teacher reports across standardized assessments to determine if lack of access to sound contributes to that child's ability to perform academic tasks in the classroom.

Considerations for Special Populations

A cochlear implant team is charged with determining a child's current level of functioning and his or her potential for development with a cochlear implant. This goal becomes even more difficult in evaluations of children who are not considered part of "mainstream" culture. For example, children who are non-mainstream dialect speakers or children who are bilingual cannot be adequately evaluated by assessments of language developed for monolingual, mainstream dialect English-speaking children. A thorough assessment of a non-mainstream language user requires additional knowledge and consideration.

To measure the language proficiency and ability of these children, professionals have some options available, but many assessments require additional work and preparation. SLPs may be able to find assessments normed on those particular special populations. For example, the Expression One Word Picture Vocabulary Test-4 (Spanish Bilingual Edition) (Martin, 2011) was normed on a group of bilingual Spanish/English-speaking children. Instruments with bilingual norms, however, are scarce currently and certainly not available for all groups of bilingual children. An SLP may also choose to evaluate a child using a criterion-referenced assessment. In this case, the SLP must determine whether or not that child should have mastered a given set of skills despite his or her language differences. Criterion-referenced assessments can be used descriptively, but of course, they should be interpreted with caution. Finally, SLPs may choose to use nonstandard methods, such as dynamic assessment, to measure growth in children from these populations. Only professionals with deep understanding of the implications of dynamic assessment procedures, which can include test-teach-retest paradigms and administration

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 4–4. Academic Skill Assessment Instrument Chart

Measure Name	*Type of Measure*	*Domains Assessed*	*Age Range*	*Information Collected*
Test of Preschool Early Literacy (TOPEL)	Norm-Referenced	Print Awareness, Phonological Awareness, Oral Vocabulary	3 to 5 years	Behavior Elicitation
Comprehensive Test of Phonological Processing (CTOPP-2)	Norm-Referenced	Phonological Awareness, Phonological Memory, Rapid Naming	5 to 24 years	Behavior Elicitation
Phonological Awareness Literacy Screening Measures (PALS-PreK, PALS-K, PALS-1-3)	Criterion-Referenced	Name Writing, Alphabet Knowledge, Beginning Sound Awareness, Rhyme Awareness, Nursery Rhyme Knowledge, Print and Word Awareness, Letter Sounds, Spelling, Word Recognition, Passage Reading, Comprehension, Fluency	Preschool to 3rd Grade	Behavior Elicitation
Boehm Test of Basic Concepts- Third Edition (BTBC)	Norm-Referenced	Basic Concept Knowledge	Kindergarten to 2nd Grade	Behavior Elicitation
Bracken School Readiness Assessment-Third Edition (BSRA)	Criterion-Referenced	Color Knowledge, Letter Knowledge, Numbers/ Counting, Comparison/ Size Knowledge, Shape Knowledge	3 to 6 years	Behavior Elicitation
Woodcock Reading Mastery Test- Third Edition (WRMT-3)	Norm-Referenced	*Subtests*: Phonological Awareness, Listening Comprehension, Letter Identification, Word Identification, Rapid Automatic Naming, Oral Reading Fluency, Word Attack, Word Comprehension, Passage Comprehension	4.5 to 79 years	Behavior Elicitation
Woodcock-Johnson Test of Achievement- III (WJTA-III)	Norm-Referenced	*Subtests*: Letter-Word Identification, Reading Fluency, Passage Comprehension, Word Attack, Reading Vocabulary, Spelling, Writing Fluency, Writing Samples, Editing,	2 to 90 years	Behavior Elicitation

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 4–4. *continued*

Measure Name	Type of Measure	Domains Assessed	Age Range	Information Collected
Woodcock-Johnson Test of Achievement-III (WJTA-III)		Spelling of Sounds, Punctuation and Capitalization, Calculation, Math Fluency, Applied Problems, Quantitative Concepts, Story Retell, Understanding Directions, Picture Vocabulary, Oral Comprehension, Sound Awareness, Academic Knowledge		
Screening Instrument for Targeting Educational Risk (SIFTER)	Criterion-Referenced	Academics, Attention, Communication, Participation, Behavior	Preschool to School Age	Teacher Report

modifications, should interpret these results (Lidz & Pena, 1996).

Although many of these methods are imperfect and/or time intensive for measuring the language ability or proficiency of these groups of children, cochlear implant teams are still obligated to evaluate these children to the best of their ability. It is not appropriate to "wait" for a child to develop adequate proficiency in the dominant language. Rather, professionals should be familiar with both languages to which a child is exposed and critically evaluate a child's performance across both languages to determine whether or not a child needs additional access to sound.

STUDENTS-HUB.com

Uploaded By: tuka abuzneid

PREIMPLANTATION THERAPY CONSIDERATIONS

Even prior to receiving a cochlear implant, speech-language therapy can be a useful tool for the purposes of intervention and evaluation, despite the fact that a child may not have access to the full range of speech sounds. The following sections describe the purpose of therapy during the preimplant period of a child's development.

Therapy Following Identification

Following identification of a child's hearing loss, many parents are unsure how best to communicate with their child. Research indicates that hearing parents of children with hearing loss do not interact with their children in the same way as parents of children with normal hearing (Lavelli, et al., 2018). As a result, children with hearing loss may have even fewer opportunities to experience typical interactions and communication than children with typical hearing, beyond those opportunities lost, due to limited access to sound.

An SLP or other early-intervention professional can be particularly valuable to families during the period immediately following identification. During this period, the interventionist can serve at least two purposes: (a) to educate parents about the future development and obstacles for their child with hearing loss and to provide support, and (b) to help parents interact with their child, ensuring that opportunities to learn basic communication skills are maximized. Most children with hearing loss are born to parents with typical hearing (Mitchell & Karchmer, 2004). As a result, at the time of identification most parents have little to no knowledge about hearing

loss or its impact on communication development. A clinical SLP is in a prime position to help parents gradually make sense of the overwhelming amount of information with which they are presented. Additionally, even without focusing on spoken language, parents can help their children with hearing loss to learn early communication skills. Children with hearing loss can learn to respond to communicative attempts, to gesture to direct attention, and to use a variety other communication methods. Interventionists can guide parents through basic communicative routines with their child with hearing loss.

Therapy Following Hearing Aid Fitting

Children eligible to receive cochlear implants generally, by definition, do not gain sufficient benefit from hearing aids (Eisenberg, Kirk, Martinez, Ying, & Miyamoto, 2004); however, even minimal residual access to sound from hearing aids can improve a child's communicative development. Basic awareness of the presence or absence of sound at any level is the first step toward developing auditory skills. An SLP can help parents work toward optimizing opportunities to connect sounds with objects and actions prior to cochlear implantation.

Drawing a child's attention to sounds in his or her environment is one of the earliest recommendations made to parents of children with hearing loss (Niparko, 2000). An SLP can help parents to recognize and draw their child's attention to sounds during everyday activities. Parents' ability to recognize and draw attention to different types of sound, such as continuous noises (i.e., a running dishwasher) or intermittent noises (i.e., a microwave beep) can assist a child's development of basic sound discrimination. These early activities set a precedent for drawing a child's attention to sound postimplantation.

Therapy Following Baseline Speech-Language Skill Evaluation

Following a child's initial speech-language evaluation, continued regular visits to an SLP allow the SLP to track the auditory, speech, and language development of a child. The SLP can provide information to a cochlear implant team about how access to sound or a lack of access to sound impacts an individual child's development. Progress monitoring, in addition to baseline data, informs a team's expectations and consequently future recommendations for a child.

Regular therapy visits prior to implantation set a precedent for ongoing therapeutic intervention post-implantation. Developing a good relationship with an SLP is important for both parents and children. These early therapy sessions can help families and SLPs to develop effective therapist-parent communication early. During this time, SLPs have the opportunity to discuss developmental principles and normal and deviant language learning. These discussions give parents early understanding of the principles that guide therapy following implantation. In addition, children learn to participate in play activities, both adult led and child led, and the therapist can begin to understand what motivates and does not motivate a child.

CONCLUSION

The SLP plays a crucial role in determining cochlear implant candidacy. The SLP can make predictions about expected communication outcomes for a child once he or she has a cochlear implant. Given the individual linguistic profiles, auditory skills, and life experiences of children with hearing loss, the role of the SLP should go beyond simply reporting test scores and performances; instead, the SLP, as a member of the cochlear implant team, should provide a sufficiently individualized profile of the child's communicative strengths and needs for the team to make a well-informed decision as to this child's potential benefit of implantation.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

Allen, S. G. (2015). *Auditory perception test for the hearing impaired*. (3rd ed.). San Diego, CA: Plural Publishing.

American Speech-Language-Hearing Association. (2001). *Knowledge and skills required for the practice of audiologic/aural rehabilitation*. http://www.asha.org/policy.

Anderson, K. L. (1989). *Screening identification for targeting educational risk*. Denver, CO: The Educational Audiology Association.

Bachman, L., & Savignon, S. (2002). The evaluation of communicative language proficiency: A critique of the ACTFL oral interview. *Modern Language Journal, 70*, 380–390.

Boehm, A. E. (2000). *Boehm Test of Basic Concepts* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Bowers, L., Huisingh, R., LoGiudice, C., & Orman, J. (2014). *The Word Test—3: Elementary*. Moline, IL: LinguiSystems.

Bracken, B. A. (2007). *Bracken School Readiness Assessment* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Carrow-Woolfolk, E. (1995). *Oral and Written Language Scales (OWLS).* Los Angeles, CA: Western Psychological Services.

Carrow-Woolfolk, E. (2014). *Test for Auditory Comprehension of Language (TACL-3)* (3rd ed.). Austin, TX: Pro-ed.

Carrow-Woolfolk, E. (2017). *Comprehensive Assessment of Spoken Language*—Second Edition *(CASL-2).* Torrance, CA: Western Psychological Services.

Dunn, D. M. (2019). *Peabody Picture Vocabulary Test* (5th ed.). Bloomington, MN: NCS Pearson.

Eisenberg, L. S. (2007). Current state of knowledge: Speech recognition and production in children with hearing impairment. *Ear and Hearing, 28*, 766–772.

Eisenberg, L. S., Kirk, K. E., Martinez, A. S., Ying, E. A., & Miyamoto, R. T. (2004). Communication abilities of children with aided residual hearing. *Archives of Otolaryngology—Head & Neck Surgery, 130*, 563–569.

Fenson, L., Marchman, V., Thal, D., Dale, P., Reznick, S., & Bates, E. (2006). *The MacArthur Communicative Development Inventories: User's guide and technical manual* (2nd ed.). Baltimore, MD: Brookes Publishing.

Fudala, J. B., & Stengall, S. (2017). *Arizona Articulation Proficiency Scale (AAPS-4)* (4th revision). Torrance, CA: Western Psychological Services.

Goldman, R., & Fristoe, M. (2015). *Goldman Fristoe Test of Articulation (GFTA-3)* (3rd ed.). Minneapolis, MN: Pearson Inc.

Invernizzi, M., Meier, J. D., Swank, L., & Juel, C. (2004). *Phonological Awareness Literacy Screening (PALS).* Charlottesville, VA: University of Virginia Press.

Invernizzi, M., Sullivan, A., Meier, J., & Swank, L. (2004). *Phonological Awareness Literacy Screening PreK (PALS-PreK)*. Charlottesville, VA: University of Virginia Press.

Khan, L., & Lewis, N. (2015). *Khan-Lewis Phonological Analysis* (3rd ed.). Minneapolis, MN: Pearson, Inc.

Lavelli, M., Majorano, M., Guerzoni, L., Murri, A., Barachetti, C., & Cuda, D. (2018). Communication dynamics between mothers and their children with cochlear implants: Effects of maternal support for language production. *Journal of Communication Disorders*, *73*, 1–14.

Lidz, C., & Pena, E. (1996). Dynamic assessment: The model, its relevance as a nonbiased approach, and its application to Latino American preschool children. *Language, Speech, and Hearing Services in Schools, 27*, 367–372.

Lonigan, C. J., Wagner, R. K., & Torgesen, J. K. (2007). *Test of Preschool Early Literacy (TOPEL).* Austin, TX: Pro-ed.

Martin, N. (2001). *Expressive One-Word Picture Vocabulary Test-4: Spanish-bilingual edition*. Novato, CA: Academic Therapy Publications.

Martin, N. A., & Brownell, R. (2010a). *Expressive One-Word Picture Vocabulary Test-4 (EOWPVT-4).* Novato, CA: Academic Therapy Publications.

Martin, N. A., & Brownell, R. (2010b). *Receptive One-Word Picture Vocabulary Test-4. (ROWPVT-4)*. Novato, CA: Academic Therapy Publications.

McCauley, R. J., & Swisher, L. (1984). Use and misuse of norm-referenced tests in clinical assessment: A hypothetical case. *Journal of Speech and Hearing Disorders, 49*, 338–348.

McNamara, T. K. (1995). Modeling performance: Opening Pandora's box. *Applied Linguistics 16*, 159–179.

Mitchell, R. E., & Karchmer, M. A. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Language Studies, 4*, 138–163.

Moeller, M. P., Hoover, B., Putman, C., Arbataitis, K., Bohnenkamp, G., & Peterson, B., . . . Stelmachowicz, P. (2007). Vocalizations of infants with hearing loss compared with infants with normal hearing, part I: Phonetic development. *Ear and Hearing, 28*, 605–627.

Moog, J. S., & Geers, A. (1990). *Early speech perception test for profoundly hearing-impaired children*. St. Louis, MO: Central Institute for the Deaf.

Niparko, J. (2000). *Cochlear implants: Principles and practices* (2nd ed.). Baltimore, MD: Lippincott, Williams and Wilkins.

Ohde, R. N., & Sharf, D. J. (1992). *Phonetic analysis of normal and abnormal speech*. New York, NY: Macmillan.

Oller, D. K., & Eilers, R. E. (1988). The role of audition in babbling. *Childhood Development, 59*, 441–449.

Phelps-Terasaki, D., & Phelps-Gunn, T. (2007). *Test of pragmatic language* (2nd ed.). East Moline, IL: Linguisystems.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Plante, E., & Vance, R. (1995). Diagnostic accuracy of two tests of preschool language. *American Journal of Speech and Language Pathology, 4*, 70–76.

Popham, W. J., & Husek, T. R. (1969). Implications of criterion referenced measurement. *Journal of Educational Measurement*, *6*, 1–9.

Edward, S., Letts, C., & Sinka, I. (2011). *New Reynell Developmental Language Scales*. London, UK: GL Assessment.

Robbins, A.M. (2005). Clinical red flags for slow progress in children with cochlear implants. *Loud and Clear, 1*, 1–8.

Rossetti, L. (1990). *Rosetti Infant-Toddler Language Scale (RI-TLS).* East Moline, IL: LinguiSystems.

Semel, E., Wiig, E., & Secord, W. A. (2004). *Clinical Evaluation of Language Fundamentals—Preschool (CELF-P2)* (2nd ed.). San Antonio, TX: The Psychological Corporation.

Storch, S. A., & Whitehurst, G. J. (2002). Oral language and code-related precursors to reading: Evidence from a longitudinal structural model. *Developmental Psychology, 38*, 934–947.

Swaminathan, H., Hambleton, R. K., & Algina, J. (1974). Reliability of criterion-referenced tests: A decision-theoretic formulation. *Journal of Educational Measurement, 11*, 264–267.

Tuohy, J., Brown, J., & Mercer-Moseley, C. (2005). *St. Gabriel's curriculum for the development of audition, language, speech, cognition, early communication, social interaction, fine motor skills, and gross motor skills* (2nd ed.). Sydney, Australia: St. Gabriel's Auditory-Verbal Early Intervention Centre.

Wagner, R. K., Torgesen, J., & Rashotte, C. (1999). *Comprehensive Test of Phonological Processing (CTOPP).* Austin, TX: Pro-ed.

Watkins, S. (2004). *SKI-HI Language Development Scale,* 2nd Edition. North Logan, UT: HOPE, Inc.

Wilkes, E. M. (2001). *Cottage Acquisition Scales for Listening, Language, and Speech* (2nd ed.). San Antonio, TX: Sunshine Cottage School for Deaf Children.

Wiig, E. H., Semel, E., & Secord, W. A. (2013). *Clinical Evaluation of Language Fundamentals (CELF-5)* (5th ed.). Bloomington, MN: Pearson, Inc.

Williams, K. (2007). *Expressive Vocabulary Test (EVT-3)* (2nd ed.). Bloomington, MN: NCS Pearson.

Woodcock, R. M. (2011). *Woodcock Reading Mastery Test* III. San Antonio, TX: Pearson.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Test of Achievement*. Itasca, IL: Riverside Publishing.

Zimmerman, I. L., Steiner, B. S., & Pond, R. E. (2010). *Preschool Language Scale (PLS-5)* (5th ed.).

STUDENTS-HUB.com Uploaded By: tuka abuzneid

5

Cochlear Implant Surgery: Clinical Implications of Variable Anatomy

Robert F. Labadie

INTRODUCTION

Cochlear implant (CI) surgery, although only a small part of the entire process of restoring hearing, lays the groundwork for subsequent rehabilitation. Surgical technique has evolved over the past four decades since FDA approval, and surgeons now concentrate on minimizing trauma in the hopes of improving audiologic performance. Recent advances have focused on the variability of cochlear anatomy and personalized surgical approaches with a goal of optimizing the interface between the electrode and the neural endings within the modiolus. Customized surgical approaches combined with postoperative imaging and specification of the final electrode-neural interface may allow programming changes to limit channel interaction, resulting in improved spectral resolution and subsequent audiologic performance. And although surgery may not the most crucial step, it is a necessary step that we are discovering has more impact upon results than previously recognized.

COCHLEAR IMPLANT RELEVANT ANATOMY

To implant a CI electrode array, one must first access the cochlea which is located deep within the skull base in the petrous portion of the temporal bone. In addition, although audiologists may not be directly involved in the surgical procedure, appreciation of what is involved improves understanding relevant to subsequent CI programming.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Mastoidectomy

Approaches to the cochlea typically involve a mastoidectomy and facial recess approach. As the name applies, a mastoidectomy involves excavating the mastoid portion of the temporal bone—the bony bulge palpable behind the ear. To do this, surgeons use high-speed drills to raster away bone in a process analogous to an archeological dig. With the aid of an operating microscope for magnification, the surgeon delineates the boundaries

of the mastoid—the wall of the external auditory canal (EAC), the tegmen (bony roof of the mastoid which separates the mastoid from the cranial vault), and the sigmoid sinus (the continuation of the internal jugular vein which drains blood from the head) (Figure 5–1A). Surgical violation of any of these structures results in corresponding sequelae. Violation of the EAC can lead to a fistula between the mastoid and ear canal, leading to infection risk; violation of the tegmen can lead to brain herniation and/or leakage of cerebrospinal fluid (CSF), which can lead to recurrent meningitis; and, violation of the sigmoid sinus can lead to bleeding, which can be life threatening. Of these three potential complications, violation of the EAC represents the most concerning risk, given the long-term risk of infection. CSF leak and sigmoid sinus bleeds are typically rectified immediately upon recognition of injury. The conclusion of a mastoidectomy is removal of an embryologic fusion plane between the mastoid and tympanic portions of the temporal bone, referred to as Koerner's septum. Once Koerner's septum is drilled away, the landscape changes dramatically as the small air cells of the lateral mastoid are replaced by a single large air cell though which a portion of the inner ear—the horizontal semicircular canal—can be visualized (Figure 5–1B).

Facial Recess

As the surgery proceeds deeper, the surgeon must identify and avoid the facial nerve. Whereas successful insertion of the CI electrode array and internal receiver is the goal of the intervention, avoidance of injury to the facial nerve is equally, if not more important, because facial nerve injury can lead to dropping of the face, oral incompetence (drooling when drinking liquids), and inability to close the eye, leading to risk of corneal ulceration. Fortunately, facial nerve injury is exceedingly rare for properly trained surgeons. Note that surgeons who perform CIs in the United States must have successfully completed a 5-year otolaryngology resident program after medical school, with most having also completed an otology, neurotology, or pediatric otolaryngology fellowship. To protect against facial nerve injury, surgeons follow sequential steps in delineating its course. After identification of the horizontal semicircular canal, the surgeon drills anteriorly to identify the short process of the incus, which points to the facial nerve as it begins its descent to the stylomastoid foramen just inferior to the horizontal semicircular canal. Using these landmarks, the surgeon carefully determines the course of the facial nerve using a diamond drill bit that minimizes damage to soft tissue, such as the nerve. To access the middle ear from this approach, a branch of the facial nerve—the chorda tympani—is usually identified so that the tympanic membrane will not be violated. The bone removed between the facial nerve and the chorda tympani is referred to as the facial recess (see Figures 5–1B and C). The surgical procedure of opening the facial recess to access the middle ear and cochlea, also called a posterior tympanotomy, is credited to CI pioneer William House.

Although other approaches to the cochlea are used—the most popular alternative being the suprameatal approach (Kronenberg, Schuster, Dietrich, & Labadie, 2004), which accesses the middle ear via the space above the incus—mastoidectomy and facial recess are the current gold standard. Keep in mind that this operation is an access operation with the intent of the surgery is to gain access to the cochlea. In general, wider access places critical structures at risk, but provides more visibility, whereas less access provides additional protection of critical structures but provides less visibility. Mastoidectomy and facial recess has been described as a funnel leading to the cochlea with the facial recess being the neck of the funnel. The take–home message is that a CI trajectory must pass through the facial recess, which may limit insertion trajectories.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Round Window

After the facial recess is opened, the middle ear is visible (see Figure 5–1C). The first structure to be visualized is usually the stapedial tendon, which tethers the capitulum of the stapes to the pyramidal process. The round window (RW) is located no more than 2 mm inferior to the stapes. The RW is poorly named because it is neither a window nor

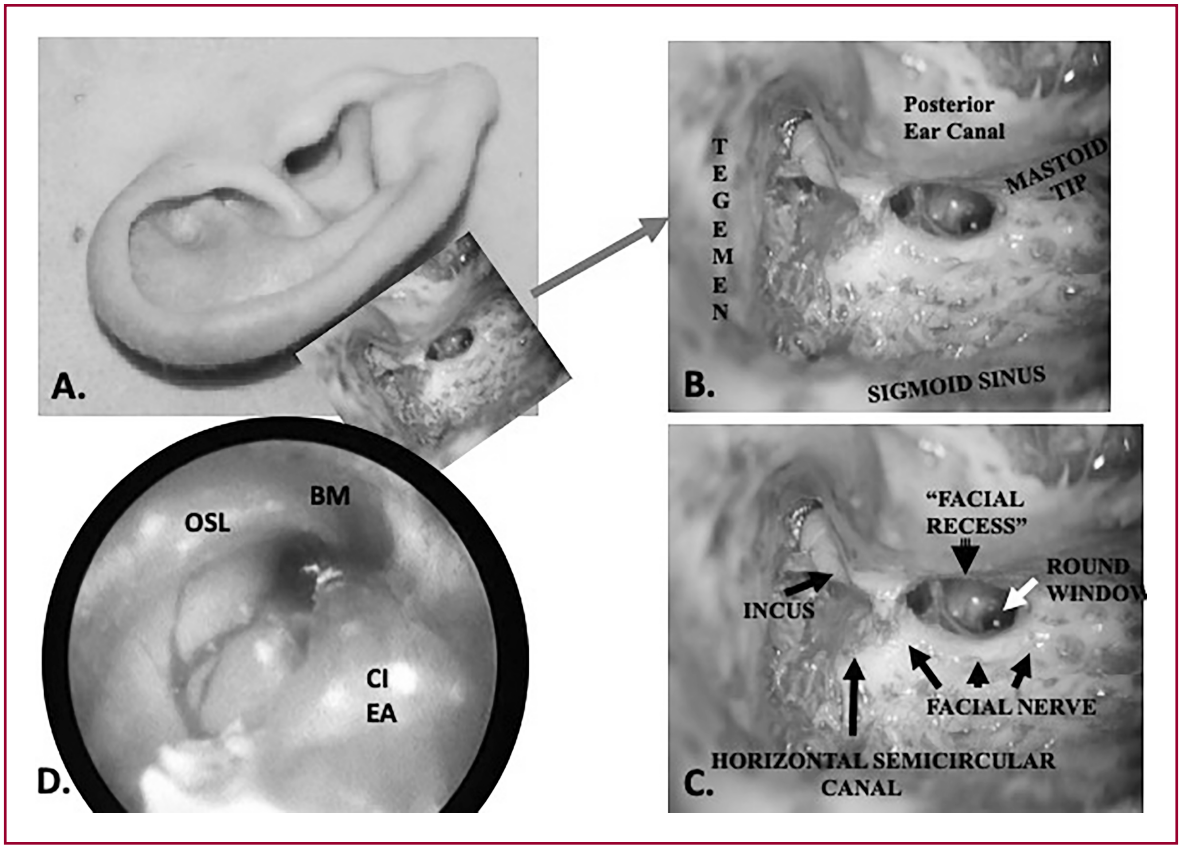


FIGURE 5–1. A–D. Mastoid anatomy. During cochlear implant surgery, the patient lays supine with the head tilted away from the operative side while the surgeon sits and uses an operating microscope to approach the ear. After initial skin incisions to expose the mastoid surface (**A**), the surgeon mills (a.k.a. drills) away bone using visual and tactile feedback to identify the tegmen, external auditory canal, and sigmoid (**B**). As the dissection progresses deeper, components of the middle and inner ear are sequentially identified in the following order (**C**): the horizontal semicircular canal lies just inferior to the incus, which "points" to the descending portion of the facial nerve. The space between a branch of the facial nerve—the chorda tympani—and the main trunk, referred to as the facial recess, is opened and the stapedial tendon and stapes are identified from which the position of the round window (RW) can be confirmed, with the RW approximately 2 mm inferior to the footplate of the stapes (**C**). Once the RW overhand is taken down, the RW membrane can be opened allowing visualization of scala tympani and sometimes the basilar membrane and basal turn of the cochlea (**D**.) CI EA = cochlear implant electrode array, OSL = osseous spiral lamina, BM = basilar membrane.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

round. The RW is protected by a niche with a bony overhang—analogous to an opening of cave. To view the RW, this overhang must be drilled away, following which the membrane can be visualized. The RW membrane is the shape of a saddle or Pringle® potato chip (technically called a hyperbolic paraboloid) and provides direct entry to the scala tympani (ST) compartment of the cochlea. This entry region is known as the hook region because the osseous spiral lamina and basilar membrane (BM)—which separates ST from the upper cochlear compartments (scala media (SM) and scala vestibuli (SV))—"hooks" inferiorly. If possible, surgeons typically enter ST by making an incision into the RW. If a surgeon needs to enlarge the RW to accommodate a CI electrode array, drilling is done anteriorly and inferiorly away from the hook to create what is referred to

as a marginal RW cochleostomy, or extended RW approach. If the constraints of the facial recess do not allow entry via the RW, a separate cochleostomy may be made.

Orientation of the Cochlea Within the Temporal Bone

Although the cochlea is adult size at birth, its orientation within the temporal bone varies with age. Human beings are born with as large a cranium as possible at the expense of the mid and lower face. Infants have "facial halves" with half of the head brain and the other half is face (i.e., the distance from the top of the forehead to the nasion (depression between the eyes) is roughly equivalent to the distance from the nasion to the chin. This anatomical arrangement causes children to look "cherubic." After about the age of two, the mid and lower face expand as the sternocleidomastoid muscle pulls on the mastoid bone causing the mastoid portion of the temporal bone to elongate and rotate. This results in the relationship between the facial recess and the cochlea to change. In infants, the facial recess plane (the plane between the facial nerve and chorda tympani) is unfavorably aligned to the desired CI trajectory, making RW insertion more difficult. In adults, the facial recess is roughly perpendicular to the desired insertion trajectory making RW insertion more readily achievable.

The above description of surgical approach is not intended to be comprehensive, but rather, it allows audiologists and speech-language pathologists to appreciate some of the thought processes going through a surgeon's mind during surgery. And the result that is perhaps most noticeable to the patient and audiologist on a daily basis is that—the internal receiver magnet—was not even addressed. In short, surgeons try and place the internal receiver as far back as is feasible so that the ear-worn processor does not encroach upon the magnetic coupling of the inductance coil. Infants' skulls continue to grow, resulting in the internal receiver moving posteriorly as a child ages, but this does not appear to affect electrode array position (Roland et al., 1998). In adults, migration of the internal receiver occasionally occurs (Maxwell & Cass, 2019) resulting in the need to surgically revise its location. And, for bilateral recipients, symmetry is desirable but not always achievable.

The Cochlea

All of the above finally allows access to the cochlea. However, one only gets a glimpse (if that) of the inside seeing the inferior aspect of the osseous spiral lamina and basilar membrane via the open RW. Using endoscopes, the distal turn of the lower basal turn may be appreciated in select cases (see Figure 5–1D). This view depends upon the characteristics of the patient's basal turn, which often has an acute inferior dip. The edge of this dip—the crista semilunaris—can be drilled away to allow a smoother (i.e., more tangential) entry into the basal turn, but this drilling comes at the risk of causing intracochlear trauma, which may impair preservation of residual hearing. The surgeon's task at this point becomes to insert a 16 to 31-mm-length electrode array into the cochlea (a spiral-shaped organ with greatest diameter about the size of a large pea) with limited to no visual guidance. This task sounds difficult at best, and current clinical results support the difficulty of this task as detailed below. But first, a bit more about the target organ: the cochlea.

It seems obvious that individual cochleae vary in size between individuals. And indeed, this has been known since 1938 when Mary Hardy published a seminal paper on 68 temporal bone specimens reporting an average total cochlear duct length of 31.52 mm with a range from 25.26 to 35.46 mm (Hardy, 1938). The original data is represented in Figure 5–2. Although this paper has been cited extensively and has been validated by others (Erixon, Hogstorp, Wadin, & Rask-Andersen, 2009), cochlear anatomical variability remains not well appreciated within the CI community, perhaps perpetuated by electrode arrays coming in generic, universal sizes. Various resources are available to appreciate the modes of variation, including bulbosity (diameter of ST, SM, and SV combined), diameter of basal turn, height from basal turn to apex, and depth of "dip" of the basal turn. These resources include the unique cochlea casks at Uppsala University in Sweden (Figure 2 from Rask-Andersen et al., 2011), various temporal

STUDENTS-HUB.com Uploaded By: tuka abuzneid

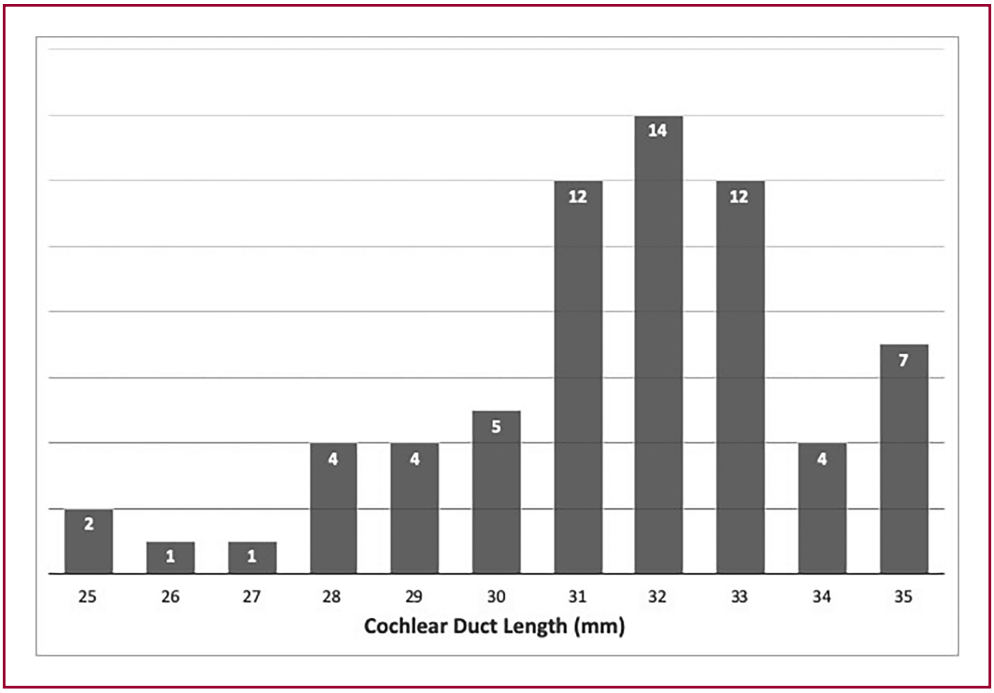
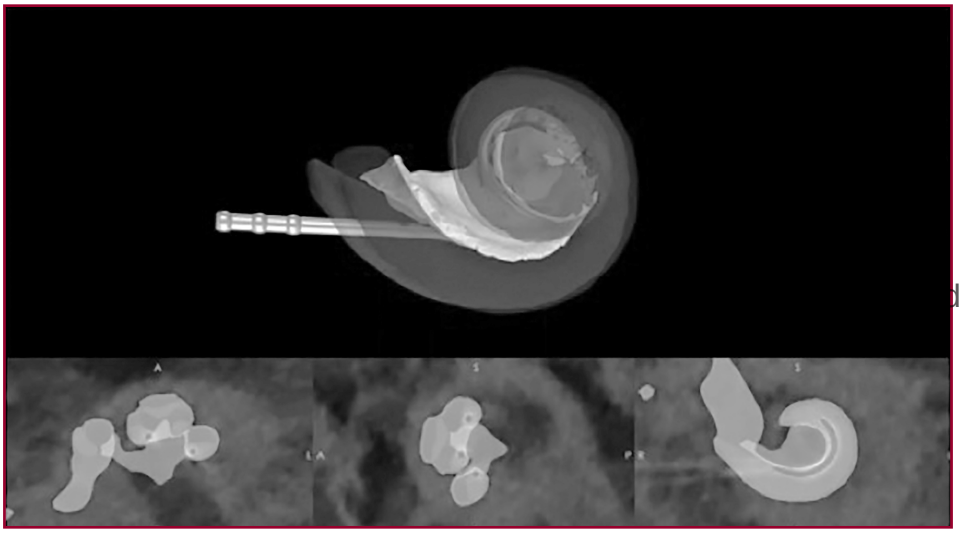


FIGURE 5–2. The variability of the length of the cochlear duct has been known since 1938 which documented differences in size between men and women (male cochleae are typically larger than female cochleae) but no differences in distribution were noted between Caucasian and African-Americans. This fact of geometric variability is not widely appreciated likely exacerbated by universally sized CI electrode arrays. In addition to variability in the length of the cochlear duct, there is great variability in terms of shape characteristics (depth of basal turn, width/bulbosity of scalae, and overall height from basal turn to apex) as well as orientation within the temporal bone (RW is more visible through facial recess in adults versus children).

STUDENTS-HUB.com



d By: tuka abuzneid

FIGURE 5–3. Image processing of postoperative CT scan showing electrode in both 3-D rendering (top panel) and axial, coronal, and parasagittal planes (bottom panels). This case shows full scala tympani insertion with good perimodiolar positioning.

bone banks, some of which have been imaged and made available (https://www.masseyeandear.org/research/otolaryngology/investigators/laboratories/eaton-peabody-laboratories/epl-imaging-resources/3d-virtual-model-of-round-window) (Gerber et al., 2017), and computer databases including those at Vanderbilt (Figure 5–3).

CLINICAL CI PLACEMENT

As one can imagine, placing a generically sized CI electrode array into an organ that varies in size will result in a wide range of outcomes. For the sake of the following discussion, we will consider electrode arrays in two broad categories—straight or precurved—based on their resting shape. All electrodes are intended to reside in ST, the largest of the three intracochlear compartments and the one closest to the auditory neural endings within the modiolus. Straight electrode arrays are designed to follow the lateral wall of ST and minimize intracochlear trauma; thus, the common practice of referring to straight electrodes as "lateral wall electrodes. Precurved electrode arrays are designed to "hug" the modiolus—hence the common practice referring to precurved electrodes as "perimodiolar electrodes"—and rest in close proximity to the auditory neural endings. Precurved electrode arrays are "straightened" using stylets (either internal wires or external sheaths) as they traverse the basal turn, after which they are threaded off the stylet when a generic depth is reached, allowing the electrode to coil as it courses beyond the basal turn. However, as we know from Mary Hardy's original paper (see Figure 5–2), there is variability even in the length of this part of the basal turn, which ranges from 9.05 to 12.19 mm. In addition to "blind" insertion beyond the RW, surgeons lack the ability to "feel" translocation from ST to SV (Schuster et al., 2015). These factors—blind insertion, variable-sized cochleae, and insertion forces below the tactile threshold of human beings—result in high variability of electrode placement locations within the cochlea.

Perhaps the worst case scenario is a CI outside the cochlea. And although one would imagine this never happens, it does occur (Figure 5–4A). Albeit infrequently, with estimated incidence below 0.5% (Yu-Lan, Lin, Oghalai, & Williamson, 2013). However, there are many other suboptimal events that occur much more frequently.

Tip Fold-Over

If a precurved electrode array is threaded off a stylet prematurely (or the patient has a large basal turn), the tip of the electrode array may fold-over on itself as it uncoils (Figure 5–4B). Although one would imagine this to be a rare event, three groups from large, experienced CI centers have independently reported an incidence of 2% to 5% with internally styleted, precurved electrodes (Cosetti et al., 2012; Zuniga et al., 2017; Trakimas, Kozin, Ghanad, Nadol, & Remenschneider., 2018). The recent multicenter European trial of an externally styleted precurved electrode array revealed a tip fold-over incidence of 4% (Aschendorff et al., 2017). Although intraoperative imaging (e.g., 2-D x-rays a.k.a. fluoroscopy or 3-D intraoperative CT scanning) is being used more and more to detect tip fold-over; for those patients who have not been imaged at least 2% likely have tip fold-over with associated poorer audiologic performance. Performance can be improved by deactivating affected electrodes and revision surgery indicated for those not responding to deactivation. Tip fold-over is rarer with straight electrodes occurring in <0.2% of cases (Dhanasingh & Jolly, 2019).

Scalar Translocation

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Another undesired outcome is translocation from ST to SV (Figure 5–4C). Although the exact mechanism has not been precisely determined, it appears to occur when the electrode reaches the end of the basal turn at approximately 180° from the RW and, instead of turning with the natural curvature of the cochlea, deflects off the lateral wall into the BM. With continued forward advancement, the electrode enters SV where it continues to coil. (An alternative hypothesis is that the electrode dissects between the internal cochlear wall

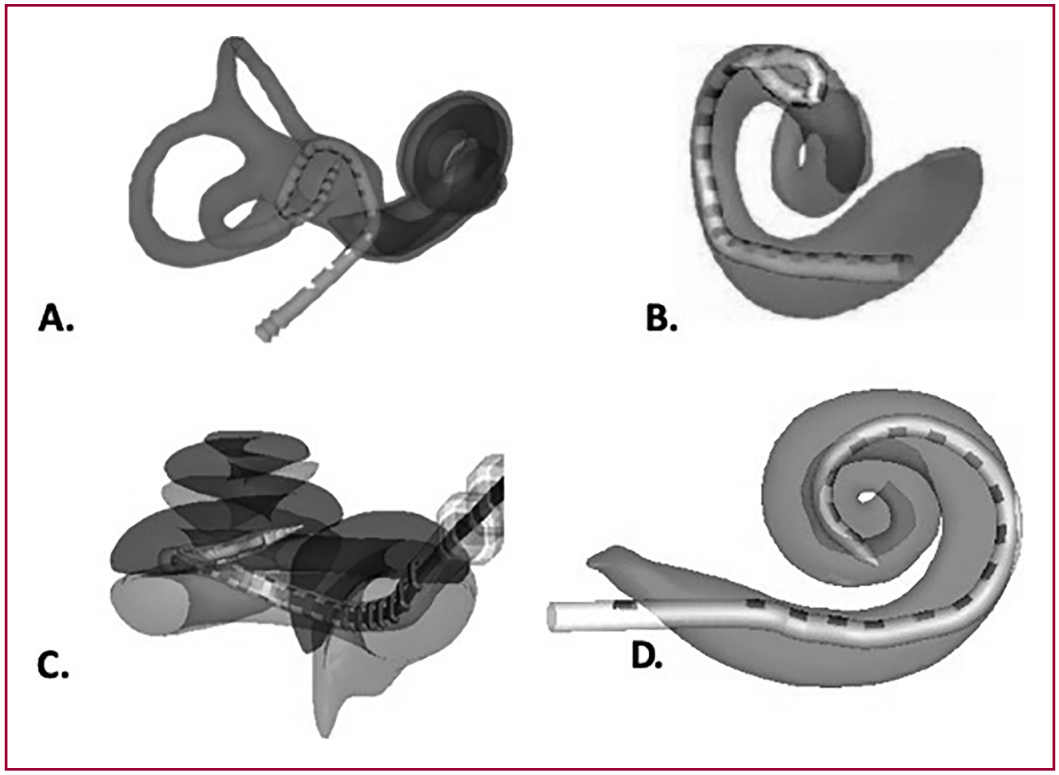


FIGURE 5–4. A–D. Three-dimensional renderings of poorly positioned CI electrode arrays. **A**. Electrode array coiled in vestibule outside of cochlea (incidence <0.5%). **B**. Tip fold-over (incidence of 2%). **C**. Translocation (incidence 30% to 50%). **D**. Basal lateralization of precurved electrode array (incidence >70%).

and the spiral ligament and enters SV via this route.) Regardless of the mechanism, the resultant translocation causes significant intracochlear trauma likely resulting in loss of residual acoustic hearing. And, the translocation pushes the precurved electrode from its intended perimodiolar position to a lateral position. How often does this occur? For internally styleted precurved electrode arrays, results from three independent CT centers indicate an incidence of 30% to 50% (Aschendorff, Kromeir, Klenzner, & Laszig, 2007; Skinner et al., 2007; Wanna et al., 2011). Data are just accumulating for externally styleted, precurved electrode arrays (e.g., CI532 or CI632), but translocation appears to occur approximately 10% of the time, which is approximately the same rate as for straight electrode arrays. Straight electrode arrays do not tend to cross at the 180° point, but rather encroach upon the BM at the apical end, as the height of the ST decreases (Avci, Nauwelaers, Lenarz, Hamacher, & Kral, 2014).

Lateralization of Precurved Electrodes

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Perhaps more insidious than tip fold-over or translocation, is lateralization of precurved electrodes arrays, which are intended to be placed in close proximity to the modiolus. This occurs when a precurved electrode array is over-inserted—the coiled apical end tends not to move much with over-insertion, which causes the basal portion to be pushed against the lateral wall (Figure 5–4D). Although such basal turn lateralization may not be associated with increased intracochlear trauma, it creates a programming dilemma for audiologists

who assume that precurved electrode arrays are perimodiolar. The reason that this is problematic is that there is a known relationship between electrode-to-modiolus distance and charge required for upper stimulation levels (Davis et al., 2016) as well as a known relationship between charge and spread of electrical excitation or channel interaction (Chatterjee & Shannon, 1998; Chatterjee, Galvin, Fu, & Shannon, 2006). Because channel interaction is a major concern for CI recipients limiting spectral resolution, precurved electrode arrays with a higher electrode-to-modiolus distance (i.e., those that are lateralized) are associated with poorer channel independence (Berg et al., 2019) and the potential for poorer outcomes. Short of specialized imaging protocols available at select academic centers, the audiologist will not know if and/or which electrodes to treat as perimodiolar versus lateral wall. How often are precurved electrodes over inserted? At least one paper indicates that this occurs >70% of the time (Wang, Dawant, Labadie, & Noble, 2017).

Extracochlear Electrodes

Whereas straight electrodes suffer less from tip fold-over and translocation (and are intended to be placed against the lateral wall so are immune to lateralization), they are more likely to have extracochlear electrodes either from shallow insertion or backing out of the electrode after insertion. And, although one may expect this to be a rare event, the data show otherwise with more than 5% to 10% of patients having at least 1 electrode unexpectedly extracochlear (Dietz, Wennström, Lehtimäki, Löppöndn & Valtonen, 2016; Holder, Kessler, Noble, Gifford, & Labadie, 2018). Perhaps more concerning is that in 40% of cases with electrocochlear electrodes, audiologists could not detect the extracochlear electrode and left those electrodes active in the patients' maps. In summary, this paper showed that in 1 out of 20 patients an extracochlear electrode was left "on" despite it being outside the cochlea (Holder et al., 2018). This is concerning given that critical high-frequency information is being delivered to extracochlear electrodes, which are not capable of providing quality neural stimulation.

CLINICAL IMPLICATIONS OF SUBOPTIMAL POSITION

If one looks critically at the above outcomes, even from a surgeon's perspective, the data do not paint a very pretty picture. With essentially blind insertion of the electrode array into the cochlea, there is at least a 2% incidence of tip fold-over, a 10% to 50% incidence of translocation, a 70% chance of lateralization of precurved electrodes, and a 5% chance that active electrodes are extracochlear. These findings beg two questions. First, do suboptimal placements affect performance? And second, if the answer to the first question is "yes," what can we do to remedy the situation?

Does Suboptimal Electrode Position Affect Performance?

The short answer to the first question is a resounding YES! In a recently published paper from our group, data from over 200 CI recipients—approximately evenly split between precurved and straight electrodes—was analyzed and fit to a generalized linear model (GLM) (Chakravorti et al., 2019). The GLM process first examines all factors included in the model to see if they affect the end result—in this case audiologic performance—and then analyzes how much each factor impacts the end result. For precurved electrode arrays, significant factors included full ST insertion, mean electrode-to-modiolus distance (a.k.a. lateralization of precurved electrode arrays and conveyed as the average distance from each electrode to the closest point on the modiolus), base insertion depth, and prelingual hearing status. For straight electrode arrays, significant factors included base insertion depth and prelingual hearing status. A brief summary of the data is that properly placed precurved electrode arrays (full ST insertion, good perimodiolar positioning) have the best audiologic outcomes. Perhaps more surprising is that group averages of both straight and precurved electrodes resulted in similar word scores (CNC ≈ 64%) but differences were detected with extremes as shown in Table 5–1 where best and worst placement (two

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 5–1. A Relatively Dramatic Difference in Audiologic Outcomes for Optimally Paced Arrays (Nontranslocated and Perimodiolarly for Precurved Arrays and Deep Insertion for Straight Arrays) Versus Suboptimal Placement

35 y.o. Male, post-lingual, 5 years CI use	*Precurved Array*	*Straight Array*
Optimal placement	**82% CNC words** (.65 expected)	**68% CNC words** (.90 expected)
Suboptimal placement	**30% CNC words** (.35 expected)	**36% CNC words** (0.10 expected)
Averaged outcome	**63.8% CNC words** *(= 82%*0.65 + 30%*0.35)*	**64.8% CNC words** *(= 68%*0.9 + 36%*0.1)*

Note. When outcomes are averaged based on expected outcomes—65% chance optimal placement for precurved and 90% chance for straight arrays—the impact of position is no longer appreciable, with roughly 64% CNC words in both groups (Chakravorti et al., 2019).

standard deviations above and below averages) for precurved and straight electrodes with respect to final word scores are shown. Precurved electrodes placed optimally would be expected to score over 80% on word scores but as low as 30% with suboptimal positioning. Straight electrodes placed optimally are expected to score nearly 70% but only 36% with suboptimal positioning. So, final electrode position seems to matter (Chakravorti et al., 2019). This is perhaps the first paper with large numbers of patients which shows that precurved electrode arrays perform better than straight electrode arrays but only when placed optimally. And, as we have shown above, optimal placement is the exception rather than the rule. Furthermore, if one does not include placement as a predictive factor but rather runs a risk-analysis assessment where the expected results of an outcome are multiplied by the predicted probability of the outcome (and/or if one averages the entire group and does not account for final position), the differences between precurved and straight arrays are not revealed.

What Can Clinicians Do?

Two millennia ago, Socrates advised, "The unexamined life is not worth living." As applied to this chapter, a clinician who does not know their results has a very low chance of improving their outcomes. This concept is perhaps more relevant for surgeons who more often are unaware of the subtleties of final outcomes with their CI recipients as compared to audiologists with whom the patients spend the bulk of their postoperative rehabilitation. Unfortunately, although pre-op scanning is standard, postop scanning is not yet standard practice; however, after reading this chapter, you will hopefully have become advocates for postoperative imaging, if only for quality assessment.

Customized Surgical Technique

Planning on Preoperative CT Scans

If seems obvious that, if given a map, surgeons would use such for surgical planning. Unfortunately, pre-operative CT scans are typically used for much more rudimentary assessments including documenting the presence of a cochlea and analyzing anatomy relevant for surgical approaches including the location of the facial nerve, the sigmoid sinus, and the tegmen. To date, only one strategy has been proposed regarding surgical planning on CT scans which involves measuring the diameter of the basal turn and using this measurement to predict overall cochlear duct length (Alexiades, Dhanasingh, & Jolly, 2015). This technique is intended to be used with MED-EL electrodes,

STUDENTS-HUB.com Uploaded By: tuka abuzneid

which offer a variety of lengths (within the U.S. market 20, 24, 26, 28, and 31 mm). However, to date, this strategy has not resulted in improved clinical outcomes other than a randomized trial comparing medium and standard length arrays where the longer electrodes where associated with improved performance regardless of the size of the cochlea (Buchman et al., 2014). There are some promising preclinical findings showing that providing textual insertion plans including insertion trajectory, depth at which to being advancing offstylet, and overall insertion depth results in more optimal final position (i.e., fewer translocations and better perimodiolar positioning) (Labadie & Noble, 2018).

Electrophysiological Monitoring

Another promising technology is recording electrophysiological responses concurrent with CI electrode insertion. This concept is widely referred to as electrocochleography or ECochG for short. In practice, an acoustic tone burst is presented to the external ear while simultaneously recording electrical activity picked up by the electrode array, typically the most apical electrode as it is advanced into the cochlea. The complex electrical response consists of waveforms that can be separated and are thought to be attributable to certain anatomical structures within the inner ear, including the cochlear microphonic (CM), which is thought to be due to outer hair cell activity, as well as the summating potential (SP; direct current shift resulting from inner and outer hair cell activity), compound action potential (CAP; aggregate VIIIth cranial nerve activity), and auditory nerve neurophonic (ANN; inner hair cell and VIIIth nerve phase locked responses to the stimulus). At present, for clinical applications, the CM is presented to the surgeon via a feedback signal (e.g., an audible alarm with volume proportional to the CM signal strength) and has been correlated with audiologic outcomes with CI (Fitzpatrick et al., 2014), preservation of residual hearing (Campbell et al., 2016), and scalar translocation (O'Connell et al., 2017). Ongoing research is focused on what corrective actions a surgeon may be able to perform in preserving ECochG signal (e.g., stop inserting and pull back, change insertion trajectory) and if such actions would improve postoperative audiologic performance.

Postoperative Correction

After surgery, audiologists are expected to continue the miracle of hearing restoration and often find themselves trying to remedy suboptimal electrode placement without even knowing if a suboptimal placement has occurred. Without postoperative imaging, audiologists are as blind as surgeons. With postoperative imaging (and image processing) decisions can be made regarding deactivation of suboptimally placed electrodes as well as the potential for expectations management. For example, if a patient has an optimally placed electrode array and is programmed appropriately ensuring low-level audibility, as well as a broad electrical dynamic range, but is performing poorly, the clinical team must question why that individual is performing poorly. Is this individual wearing the processor all waking hours? Does this individual have any neurocognitive concerns? Conversely, if we have a patient with a suboptimally placed electrode array, but that patient is upset that she is not achieving above-average performance, the clinician can use this information to explain that the patient is performing as expected. And with this information, audiologists can still attempt additional personalized programming in an attempt to improve patient outcomes.

Extra-Cochlear Electrodes

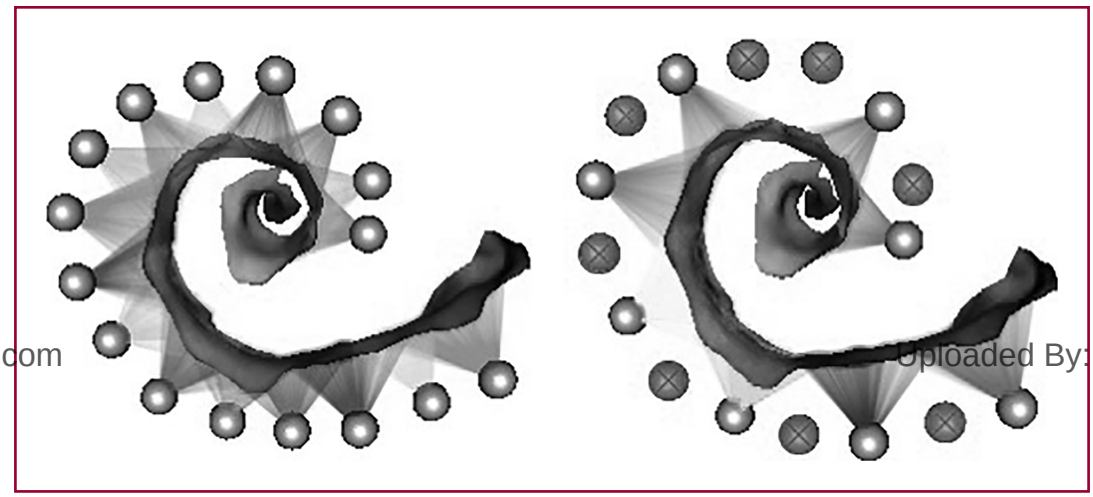
The most suboptimal electrode placement is outside the cochlea. In a recent publication, the incidence of extracochlear electrodes was found to be 13.4% with over 40% of these extracochlear electrodes missed by audiologists (Holder et al., 2018). In this cohort from a large, experience CI center, 1 out of 20 patients had at least one extracochlear electrode active. Fortunately, these patients were reprogrammed based on the imaging results. However, postoperative imaging is not yet standard of care and one can only wonder how many of the estimated 750,000 CI recipients have extracochlear electrodes turned "on." If the incidence is similar to that reported by Holder and colleagues,

STUDENTSHUB.com Uploaded By: tuka abuzneid

over 40,000 CI recipients have active extracochlear electrodes that have not been accurately identified by audiologists.

Deactivation of Electrodes Interfering with One Another

The concept of deactivating CI electrodes is not new and is a strategy employed by audiologists in the hopes of improving clinical outcomes and/or reducing unwanted side effects (e.g., facial nerve stimulation). Various strategies have been employed based on psychoacoustical responses and/or patient perceived subjective improvement (e.g., Henshall & McKay, 2001; Zwolan, Collins, & Wakefield, 1997; Bierer & Litvak, 2016; Vickers, Degun, Canas, Stainsby, & Vanpoucke, 2016). But such strategies are labor and time intensive. Another option is to deactivate, based on postoperative imaging, in which competitive neighboring electrodes are identified. Such competition occurs where the neighboring electrode may be closer to the site of neural stimulation, warranting deactivation of the electrode and using the neighbor to present its signal (Figure 5–5) (Noble, Labadie, Gifford, & Dawant, 2013). Initial reports on adult (Noble et al., 2014) and pediatric (Noble, Gifford, Hedley-Williams, Dawant, & Labadie, 2016) populations have proved promising with improvement in word and sentence scores both in quiet and noise, as well as improved spectral resolution supporting the underlying hypothesis that the deactivations result in a clear signal. Translation to other sites has begun (McRackan et al., 2017) with the intent that more and more centers will find such strategies effective. Overall, approximately 70% of patients find deactivation subjectively or objectively better than standard of care programming and chose the deactivated map for long-term use. Although this is but one example of a deactivation strategy, use of it or another deactivation approach is predicted to result in better performance as compared with leaving all electrodes active (Sagi & Svirsky, 2018). Perhaps the best electrode array would be one with the most electrodes possible with the intent of deactivating a select group based on a combination of imaging-derived distance and behavioral percept.



STUDENTS-HUB.com Uploaded By: tuka abuzneid

FIGURE 5–5. Image-guided cochlear implant programming involves deactivating electrodes that interfere with their neighbors providing a clearer signal to the modiolus. In this schematic, 16 electrodes (gray spheres, left panel) are shown in relation to the tonotopically mapped modiolar endings within the osseous spiral lamina. Also shown in the various cones are spread of current. When interfering electrodes are deactivated—in the right panel electrodes 2, 4, 5, 7, 9, 11, and 13 are turned off and cone of current spread removed—nonoverlapping information that covers the entire frequency spectrum is presented to the neural endings.

As mentioned in the beginning of this section, to do postop correction one must know the postop position that requires postoperative CT scanning, which is not yet standard clinical practice. If only for detecting the most egregious CI electrode misplacements—0.37% arrays completely outside the cochlea (Yu-Lan et al., 2013), 2% with tip fold-over (Cosetti et al., 2012; Zuniga et al., 2017; Trakimas, Kozin, Ghanad, Nadol, & Remenschneider, 2018), and 5% with at least one extracochlear electrode not detectable by audiology (Holder et al., 2018) —why is postoperative imaging not routinely performed? The two biggest reasons are cost and radiation exposure. Cost seems to be the easiest to address as CT scanning prices continuing to drop with out-of-pocket expenses to patients likely $500 or less. Radiation exposure is somewhat more concerning, however, and is being ameliorated using as-low-as-reasonable protocols and low-radiation cone beam CT scanners. As with any other health care decisions, patients and clinicians must consider the risks and benefits and decide if those benefits outweigh the risks. With that in mind, is it worth a small amount of radiation exposure for a postoperative low-dose CT scan (radiation exposure on the order of five roundtrip airplane trips from New York City to Paris (https://www.cdc.gov/nceh/radiation/air_travel.html, http://jag.cami.jccbi.gov/cariprofile.asp) and less than that of a screening mammogram (https://xorantech.com/products/minicat/) to detect potentially correctable misplacements?

TEAM APPROACH

Implied throughout this chapter, but not explicitly stated until now, is that cochlear implantation is a team effort—surgeons, audiologists, and speech-language pathologists need to work together to get the best outcomes. Moreover, at least at our institution, we have found that imaging professionals, including computer science engineers, add immeasurably to improving outcomes. At Vanderbilt, we have found that appreciation for each professional's role within the process is vital in building a cohesive team. To accomplish this, we expose all members of the team to what the other members do (e.g., audiologists attempt CI electrode array insertion in the temporal bone lab and surgeons attend postoperative programming sessions).

As has been reiterated elsewhere in this book, we are embarking on the second generation of CI technology, with the first generation having clinically translated the technology with reasonable outcomes, namely, restoring the ability to understand speech and communicate effectively in quiet settings. To advance the field, and better restore hearing (e.g., improve hearing in noisy environments), customized treatment paradigms will be necessary and likely involve customized surgical approaches based largely on imaging and electrophysiological responses during insertion, customized postoperative programming based on final position of the electrode array combined with (hopefully) measures of neural survival, and perhaps use of adjuvant pharmacological therapies, which may include steroids and/or neurotrophic agents. To achieve these successes, teams of scientists with expertise in multiple fields will need to work together with the focus on improving patient outcomes.

REFERENCES

Alexiades, G., Dhanasingh, A., & Jolly, C. (2015). Method to estimate the complete and two-turn cochlear duct length. *Otology & Neurotology*. *36*(5), 904–907.

Aschendorff, A., Briggs, R., Brademann, G., Helbig S., Hornung, J., Lenarz, T., . . . James C. J. (2017). Clinical investigation of the Nucleus Slim Modiolar Electrode. *Audiology & Neurotology, 22*(3), 169–179.

Aschendorff, A., Kromeier, J., Klenzner, T., & Laszig, R. (2007). Quality control after insertion of the nucleus contour and contour advance electrode in adults. *Ear and Hearing, 28*(2 Suppl), 75S–79S.

Avci, E., Nauwelaers, T., Lenarz, T., Hamacher, V., & Kral, A. (2014). Variations in microanatomy of the human cochlea. *Journal of Comparative Neurology, 522*, 3245–3261.

Berg, K. A., Noble, J. H., Dawant, B. M., Dwyer, R. T., Labadie, R. F., & Gifford, R. H. (2019). Speech recognition as a function of the number of channels in perimodiolar electrode recipients. *Journal of the Acoustical Society of America, 145*(3), 1556–1564.

Bierer, J. A., & Litvak, L. (2016). Channel interaction through cochlear implant programming may

STUDENTS-HUB.com Uploaded By: tuka abuzneid

improve speech perception: Current focusing and channel deactivation. *Trends in Hearing, 20*, 1–12.

Buchman, C. A., Dillon, M. T., King, E. R., Adunka, M. C., Adunka, O. F., & Pillsbury, H. C. (2014). Influence of cochlear implant insertion depth on performance: A prospective randomized trial. *Otology & Neurotology, 35*(10), 1773–1779.

Campbell, L., Kaicer, A., Sly, D., Iseli, C., Wei, B., Briggs, R., & O'Leary, S. (2016). Intraoperative real-time cochlear response telemetry predicts hearing preservation in cochlear implantation. *Otology & Neurotology, 37*, 332–338.

Chatterjee, M., Galvin, J. J., Fu. Q. J., & Shannon, R. V. (2006). Effects of stimulation mode, level and location on forward-masked excitation patterns in cochlear implant patients. *Journal of the Association for Research in Otolaryngology, 7*, 15–25.

Chatterjee, M., & Shannon, R. V. (1998). Forward masked excitation patterns in multielectrode electrical stimulation. *Journal of the Acoustical Society of America*, *103*, 2565–2572.

Chakravorti, S., Noble, J. H., Gifford, R. H., Dawant, B. M., O'Connell, B., Wang, J., & Labadie, R. F. (2019). Further evidence of the relationship between cochlear implant electrode positioning and hearing outcomes. *Otology & Neurotology*, epub ahead of print, 2019 March 13.

Cosetti, M. K., Troob, S. H., Latzman, J. M., Shapiro, W. H., Roland, J. T., Jr, & Waltzman, S. B. (2012). An evidence-based algorithm for intraoperative monitoring during cochlear implantation. *Otology & Neurotology, 33*(2), 169–176.

Davis, T. J., Zhang, Y., Gifford, R. H., Dawant, B. M., Labadie, R. F., & Noble, J. H. (2016). Relationship between electrode-to-modiolus distance and current levels for adults with cochlear implants. *Otology & Neurotology, 37*(1), 31–37.

Dhanasingh, A., & Jolly, C. (2019). Review on cochlear implant electrode array tip fold-over and scalar deviation. *Journal of Otology, 14*(3), 94–100.

Dietz, A., Wennström, M., Lehtimäki, A., Löppönen, H., & Valtonen, H. (2016). Electrode migration after cochlear implant surgery: More common than expected? *European Archives of Otorhinolaryngology, 273*(6), 1411–1418.

Erixon, E., Hogstorp, H., Wadin, K., & Rask-Andersen, H. (2009). Variational anatomy of the human cochlea: Implications for cochlear implantation. *Otology & Neurotology, 30*(1), 14–22.

Fitzpatrick, D. C., Campbell, A., Choudhury, B., Dillon, M., Forgues, M., Buchman, C. A., & Adunka, O. F. (2014). Round window electrocochleography just prior to cochlear implantation: Relationship to word recognition outcomes in adults. *Otology & Neurotology, 35*, 64–71.

Gerber, N., Reyes, M., Barazzetti, L., Kjer, H. M., Vera, S., Stauber, M., . . . Ballester, M. A. G. (2017). A multiscale imaging and modelling dataset of the human inner ear. *Scientific Data, 19*(4), 170132.

Hardy M. (1938). The length of the organ of Corti in man. *American Journal of Anatomy, 62*(2), 291–311.

Henshall, K.R., & McKay, C.M., 2001. Optimizing electrode and filter selection in cochlear implant speech processor maps. *Journal of the American Academy of Audiology, 12*, 478–489.

Holder, J. T., Kessler, D. M., Noble, J. H., Gifford, R. H., & Labadie, R. F. (2018). Prevalence of extracochlear electrodes: CT scans, cochlear implant maps, and operative reports. *Otology & Neurotology, 39*(5), e325–e331.

Kronenberg, J., Baumgartner, W., Migirov, L., Dagan, T., & Hildesheimer, M. (2004). The suprameatal approach: An alternative surgical approach to cochlear implantation. *Otology & Neurotology, 25*(1), 41–44.

Labadie, R. F., & Noble, J. H. (2018). Preliminary Results with image-guided cochlear implant insertion iechniques. *Otology & Neurotology*, *39*(7), 922–928.

Maxwell, A. K., & Cass, S. P. (2019). Cochlear Implant receiver-stimulator migration using the subperiosteal pocket technique: Objective measurements of early and late positioning. *Otology & Neurotology, 40*(3), 328–334.

McRackan, T. R., Noble, J. H., Wilkinson, E. P., Mills, D., Dietrich, M. S., Dawant, B. M., . . . Labadie, R. F. (2017). Implementation of image-guided cochlear implant programming at a distant site. *Otolaryngology-Head and Neck Surgery, 156*(5), 933–937.

Noble, J. H., Labadie, R. F., Gifford, R. H., & Dawant, B. M. (2013). Image-guidance enables new methods for customizing cochlear implant stimulation strategies. *IEEE Transactions Neural Systems Rehabilitation Engineering, 21*(5), 820–829.

Noble, J. H., Gifford, R. H., Hedley-Williams, A. J., Dawant, B. M., & Labadie, R. F. (2014). Clinical evaluation of an image-guided cochlear implant programming strategy. *Audiology & Neurootology, 19*(6), 400–411.

Noble, J. H., Hedley-Williams, A. J., Sunderhaus, L., Dawant, B. M., Labadie, R. F., Camarata, S. M., & Gifford, R. H. (2016). Initial results with image-guided cochlear implant programming in children. *Otology & Neurotology, 37*(2), e63–69.

O'Connell, B. P., Holder, J. T., Dwyer, R. T., Gifford, R. H., Noble, J. H., Bennett, M. L., . . . Labadie, R. F. (2017). Intra- and postoperative electrocochleography may be predictive of final electrode position and postoperative hearing preservation. *Frontiers in Neuroscience, 29*(11), 291.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Rask-Andersen, H., Erixon, E., Kinnefors, A., Löwenheim, H., Schrott-Fischer, A., & Liu, W. (2011). Anatomy of the human cochlea—implications for cochlear implantation. *Cochlear Implants International, 12* (Suppl. 1), S8–13.

Roland, J. T. Jr, Fishman, A. J., Waltzman, S. B., Alexiades, G., Hoffman, R. A., & Cohen, N. L. (1998). Stability of the cochlear implant array in children. *Laryngoscope, 108*(8 Pt. 1), 1119–1123.

Sagi, E., & Svirsky, M. A. (2018). Deactivating cochlear implant electrodes to improve speech perception: A computational approach. *Hearing Research, 370*, 316–328.

Schuster, D., Kratchman, L.B., & Labadie, R.F. (2015). Characterization of intracochlear rupture forces in fresh human cadaveric cochleae. *Otology & Neurotology, 36*(4), 657–661.

Skinner, M. W., Holden, T. A., Whiting, B. R., Voie, A. H., Brunsden, B., Neely, J. G., . . . Finley, C. C. (2007). In vivo estimates of the position of advanced bionics electrode arrays in the human cochlea. *Annals of Otology, Rhinology, Laryngology Supplement, 197*, 2–24.

Trakimas, D. R., Kozin, E. D., Ghanad, I., Nadol, J. B. Jr, & Remenschneider, A. K. (2018). Human otopathologic findings in cases of folded cochlear implant electrodes. *Otology & Neurotology, 39*(8), 970–978.

Vickers, D., Degun, A., Canas, A., Stainsby, T., & Vanpoucke, F. (2016). Deactivating cochlear implant electrodes based on pitch information for users of the ACE strategy. *Advances in Experimental Medicine and Biology, 894*, 115–123.

Wanna, G. B., McRackan, T. R., Dawant, B. M., Dietrich, M. S., Watkins, L. D., Rivas, A., . . . Labadie, R. F. (2011). Assessment of electrode placement and audiologic outcomes in bilateral cochlear implantation. *Otology & Neurotology, 32*(3), 428–423.

Wang, J., Dawant, B. M., Labadie, R. F., & Noble, J. H. (2017). Retrospective evaluation of a technique for patient-customized placement of precurved cochlear implant electrode arrays. *Otolaryngology-Head and Neck Surgery, 157*(1), 107–112.

Yu-Lan, M. Y., Lin, J. W., Oghalai, J. S., & Williamson, R. A. (2013). Cochlear implant electrode misplacement: Incidence, evaluation, and management. *Laryngoscope, 123*(3), 757–766.

Zuniga, M. G., Rivas, A., Hedley-Williams, A., Gifford, R. H., Dwyer, R., Dawant, B. M., . . . Labadie, R. F. (2017). Tip Fold-over in cochlear implantation: Case series. *Otology & Neurotology, 38*(2), 199–206.

Zwolan, T.A., Collins, L.M., & Wakefield, G.H., 1997. Electrode discrimination and speech recognition in postlingually deafened adult cochlear implant subjects. *The Journal of the Acoustical Society of America, 102*, 3673–3685.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

6

Nontraditional Candidates for Cochlear Implantation

René H. Gifford

INTRODUCTION

The FDA-labeled indications for conventional adult cochlear implant candidacy have remained unchanged since 2005. Pediatric-labeled indications have not been modified since 2000. Furthermore, Medicare's National Coverage Determination outlining cochlear implantation criteria was last updated in July 2005. As stated in Chapter 1, in order for the implant manufacturers to broaden or expand the labeled indications (also referred to as candidacy criteria), they must complete an FDA-approved clinical trial requiring a panel-track supplement. The reason is that the FDA has stated in its code of federal regulations that labeled indications must be supported by substantial evidence of effectiveness based on data collected from well-controlled studies. This is a time intensive and costly endeavor; thus, although technology and clinical practice has evolved rapidly over the past decade, the FDA-labeled indications remain unchanged.

Clinics across the country are routinely implanting patients who may not perfectly fit the implant candidate profile as specified in the labeled indications. The reason that this is occurring is that the peer-reviewed literature and clinical practice have both provided us with evidence supporting the expansion of implant criteria. This chapter describes the relevant literature, current clinical practices, and the importance of evaluating the whole patient for the determination of implant candidacy for both adults and children.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

BARRIERS TO COCHLEAR IMPLANTATION

As of early 2019, there had been approximately 120,000 cochlear implant recipients in the U.S., with 60% of those being adult recipients (Menapace, 2019). Goman and Lin (2016) reported that there were approximately 2.1 million Americans aged 20 years and older with severe-to-profound hearing loss (Goman & Lin, 2016). Given that

approximately 72,000 adults have received cochlear implants in the U.S., that translates to an approximate 3.4% implantation rate for the 2.1 million adults with severe-to-profound bilateral sensorineural hearing. In contrast to the extremely low utilization rate for adult cochlear implantation in the U.S., approximately 50% to 55% all pediatric implant candidates between the ages of 1 and 6 years are receiving implants in the U.S. (Bradham & Jones, 2008; Sorkin, 2013; Sorkin & Buchman, 2016). However, this rate is considerably lower than other developed countries, such as Australia and Sweden, in which up to 98% of children with bilateral severe-to-profound hearing loss are receiving cochlear implants (Sorkin & Buchman, 2016).

The underutilization of cochlear implant technology has many possible underlying sources. One possibility is the lack of patient awareness about cochlear implants. Cochlear implants have been referred to as the most successful sensory prosthesis invented (Wilson & Dorman, 2008). Given the success of cochlear implants and the ubiquity of related research in the peer-reviewed literature in otology, hearing, deaf education, speech, and language, one would assume that public awareness is also widespread. This, however, is not the case. The lack of widespread public awareness regarding cochlear implants, including function, candidacy, and insurance coverage, is a large part of the mission for a number of not-for-profit advocacy and awareness foundations, including the American Cochlear Implant Alliance, Cochlear Implant Awareness Foundation, Hearing Loss Association of America, Alexander Graham Bell Association, Songs for Sound, the CARE project, Hearing Health Foundation, Hands and Voices, and others.

Another possible explanation for the underutilization of cochlear implants is a matter of finances. Stern and colleagues (2005) examined the ZIP codes of cochlear implant recipients, the associated median income in those codes, and found that more children living in higher socioeconomic areas had cochlear implants (Stern, Yeuh, Lewis, Norton, & Sie, 2005). This finding is cause for concern given that epidemiologic research has shown a greater prevalence of childhood hearing loss in lower socioeconomic areas (Mehra, Eavey, & Keamy, 2009). Finances also present a barrier to implant technology for adult candidates. There is an increasing trend for state Medicaid services to exclude cochlear implant coverage for individuals over 21 years of age. At the time of chapter preparation, approximately 60% of states in the United States were providing Medicaid coverage for cochlear implants in adults over 21 years (Sorkin, 2019).

Another financial burden exists for those individuals not meeting income requirements for Medicaid, but whose employer does not offer health insurance coverage. According to the 2017 U.S. Census and 2018 Current Population Survey and Annual Social and Economic Supplement (CPS ASEC), and the 2018 American Community Survey (ACS), approximately 28.5 million Americans of all ages were uninsured in 2011 (Berchick, Hood, & Barnett, 2018). Those people who are uninsured may choose to forego health insurance coverage completely or purchase high-deductible health plans that may exclude cochlear implantation. Such exclusionary policies may only become problematic in cases of sudden or acquired adult hearing loss, leaving the policyholder without cochlear implant coverage and lacking the finances to pay for the surgery, device, and external activation kit, all of which is estimated to cost between $55,000 and >$125,000 depending on geographic location.

Another barrier to implant technology may be related to the lack of professional knowledge among referring providers. This is not meant to solely implicate primary care physicians (Cohen, Labadie, & Haynes, 2005; Wu, Zardouz, Rothholtz, German, & Djalilian, 2010) and hearing aid dispensers (Huart & Sammeth, 2009) who may expectedly lack current knowledge about cochlear implant criteria. Even general ENT physicians and nonimplant audiologists may not fully recognize the audiologic profile of the modern-day implant candidate. Unless a professional has actively sought continuing education opportunities in the area of cochlear implant candidacy and outcomes, he or she may be under the impression that an individual must have profound bilateral deafness in order to qualify and derive benefit.

Yet another potential barrier to implantation relates to a lack of cochlear implant referrals from hearing aid dispensers and private-practice audi-

STUDENTS-HUB.com Uploaded By: tuka abuzneid

ologists for fear of losing hearing aid patients. Though no data exist suggesting that hearing aid dispensers and/or private-practice audiologists are reluctant to refer for cochlear implant evaluation, it is not an unreasonable supposition. For professionals whose income relies either solely or predominantly upon hearing aid sales, a cochlear implant referral may be perceived as a lost patient; however, this is absolutely not the case. There are an increasing number of studies demonstrating that individuals making use of a cochlear implant and a contralateral hearing aid (also referred to as bimodal hearing) are able to integrate the electric and acoustic signals to derive significant benefit for speech recognition in quiet and in noise as well as for the recognition of music. The reality is that the bimodal listener can continue to be a unilateral hearing aid patient for many years and will respect the referring audiologist for knowing the limitations of hearing aids and recognizing when to appropriately refer for implant evaluation. In order to maintain a respectful professional relationship between referring audiologist and the cochlear implant center, it is important that cochlear implant providers send the implant recipient back to the referring audiologist for future hearing aid upgrades. This does not mean that the cochlear implant audiologist cannot program both the hearing aid and cochlear implant—which is most convenient for the patient—but sending the patient to his or her original audiologist for major hearing aid follow-up and upgrades demonstrates professional respect and nurtures the referral pathway for future patients.

EVIDENCE FOR THE EXPANSION OF COCHLEAR CANDIDACY

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Adults

A number of studies have reported speech understanding outcomes for adult implant recipients who had not met all FDA-labeled indications for cochlear implantation. In all studies, the adult cochlear implant recipients exhibited significant improvements in speech recognition in even the bilateral, best-aided condition (Adunka, Buss, Clark, Pillsbury, & Buchman, 2008; Amoodi et al., 2011; Firszt, Reeder, Holden, & Dwyer, 2018; Gifford, Dorman, Shallop, & Sydlowski, 2010; Sladen et al., 2017; Tremblay, Bergeron, & Ferron, 2008).

Figure 6–1 summarizes the findings of the above-cited studies on nontraditional adult implant recipients. The degree of benefit for the bilateral aided condition (bimodal-preop bilateral hearing aids) averaged across the six studies was 38-percentage points for CNC word recognition and 29-percentage points for sentence recognition, though postoperative sentence recognition scores were limited by ceiling effects for many of the participants. In addition to these studies, there are also a number of papers demonstrating significant

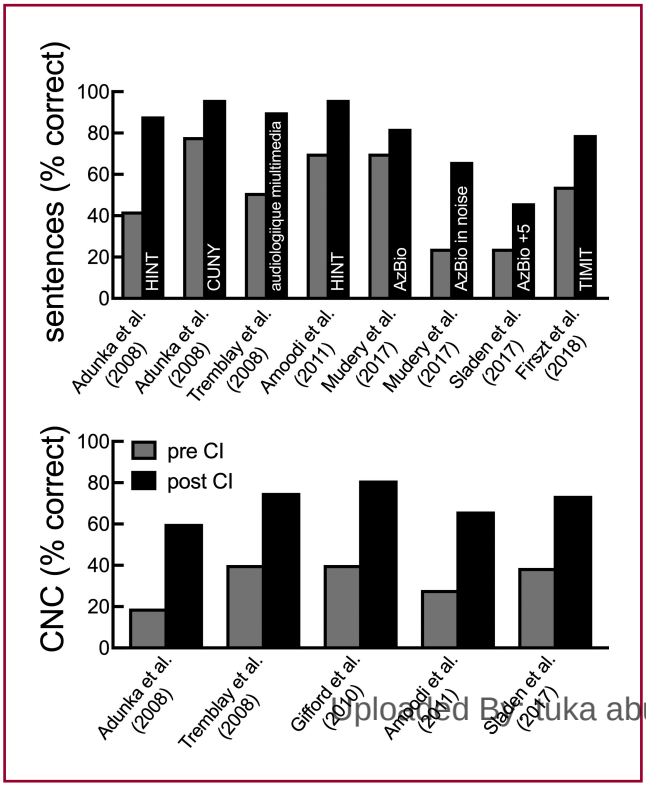


FIGURE 6–1. Comparison of pre- and postimplant sentence recognition and consonant nucleus consonant (CNC) word recognition across studies investigating the efficacy of cochlear implantation for adult candidates with significant residual hearing and/or above criterion preoperative speech recognition. HINT Hearing in Noise Test; CUNY City University of New York; TIMIT Texas Instruments Massachusetts Institute of Technology.

benefit from cochlear implantation for adults with asymmetric hearing losses when comparing bimodal speech recognition to the better ear alone (Arndt et al., 2017; Firszt, Holden, Reeder, Cowdrey, & King, 2012; Firszt et al., 2018; Ketterer et al., 2018; Sanhueza, Manrique, Huarte, de Erenchun, & Manrique, 2016; van Loon, Smits, Smith, Hensen, & Merkus, 2017). Clearly, the research on nontraditional adult implant recipients has been unequivocal in demonstrating improvement in speech perception. In fact, the point of diminishing returns has yet to be identified.

At the time of chapter preparation, both Cochlear Americas and MED-EL had been actively enrolling adult participants in an FDA-approved study of revised indications for cochlear implantation. The criteria for preoperative speech understanding for both clinical trials were bilateral moderate-to-profound sensorineural hearing loss, CNC word recognition up to 40% in the ear to be implanted, and no greater than 50% CNC word recognition in the contralateral ear. Thus, it is likely that adult cochlear implant criteria will be "officially" expanded in the near future and will likely include monosyllabic word recognition as the criterion, as indicated in Chapter 1. This path will continue to be investigated via evidence-based practices as we study the population who might benefit from cochlear implantation and, above all, strive to do no harm.

Children

Cochlear implant programs affiliated with large academic medical centers have been, for some time, routinely implanting children with sensorineural hearing loss who do not meet the "typical" implant candidacy profile. The reason that this is generally considered common practice is that evidence exists for the expansion of current implant criteria for children with significant hearing loss who are not making expected progress for auditory, speech, and language skills with appropriately fitted hearing aids and recommended intervention. Historically, there have been a number of reports advocating for the expansion of pediatric cochlear implant criteria (Cowan et al., 1997; Eisenberg, Martinez, Holowecky, & Pogorelsky, 2002; Gantz et al., 2000; Mondaine et al., 2002; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Winton, Hollow, & Dettman, 2002). There have been other reports of children with residual hearing successfully combining electric and acoustic stimulation across ears for bimodal hearing (Beijen, Mylanus, Leeuw, & Snik, 2008; Cheng et al., 2018; Ching et al., 2005; Ching, Incerti, Hill, & van Wanrooy, 2006; Ching, Psarros, Hill, Dillon, & Incerti, 2001; Choi et al., 2017; Holt, Kirk, Eisenberg, Martinez, & Campbell, 2005; Mok, Galvin, Dowell, & McKay, 2010; Straatman, Rietveld, Beijen, Mylanus, & Mens, 2010) and well as an emerging literature on pediatric cochlear implant recipients with preserved acoustic hearing in the implanted ear (Brown, Hullar, Cadieux, & Chole, 2010; Bruce et al., 2014; Carlson et al., 2017; Manjaly et al., 2018; Park, Teagle, Gagnon, Woodard, & Brown, 2019; Rajan et al., 2018; Skarzynski, Lorens, Dziendziel, & Skarzynski, 2019; Skarzynski, Lorens, Piotrowska, & Anderson, 2007; Skarzynski et al., 2016). However, over the past decade there have only been a handful of peer-reviewed papers dealing specifically with the issue of expanded criteria for pediatric cochlear implantation—that is, implanting children whose aided speech recognition and/or audiometric thresholds are outside the labeled indications.

In studies evaluating outcomes for children implanted in an "off-label" approach, pediatric cochlear implant recipients exhibited significant improvements in speech recognition in even in the bilateral, best-aided condition (Cadieux, Firszt, & Reeder, 2013; Carlson et al., 2014; Dettman et al., 2004; Skarzynski et al., 2019). Figure 6–2 displays mean pre- and postimplant speech recognition in the bilateral aided condition, which included bilateral hearing aids preoperatively and bimodal hearing postoperatively. Mean improvement across the four studies was 32 percentage points, ranging from 20 percentage points for monosyllabic words in noise at +8 dB SNR (Cadieux et al., 2013) to 45 percentage points for BKB sentences in quiet (Dettman et al., 2004). It is noteworthy that two of these studies included children with asymmetric hearing losses (Cadieux et al., 2013; Carlson et al., 2014), and thus the ear that was

STUDENTS-HUB.com Uploaded By: tuka abuzneid

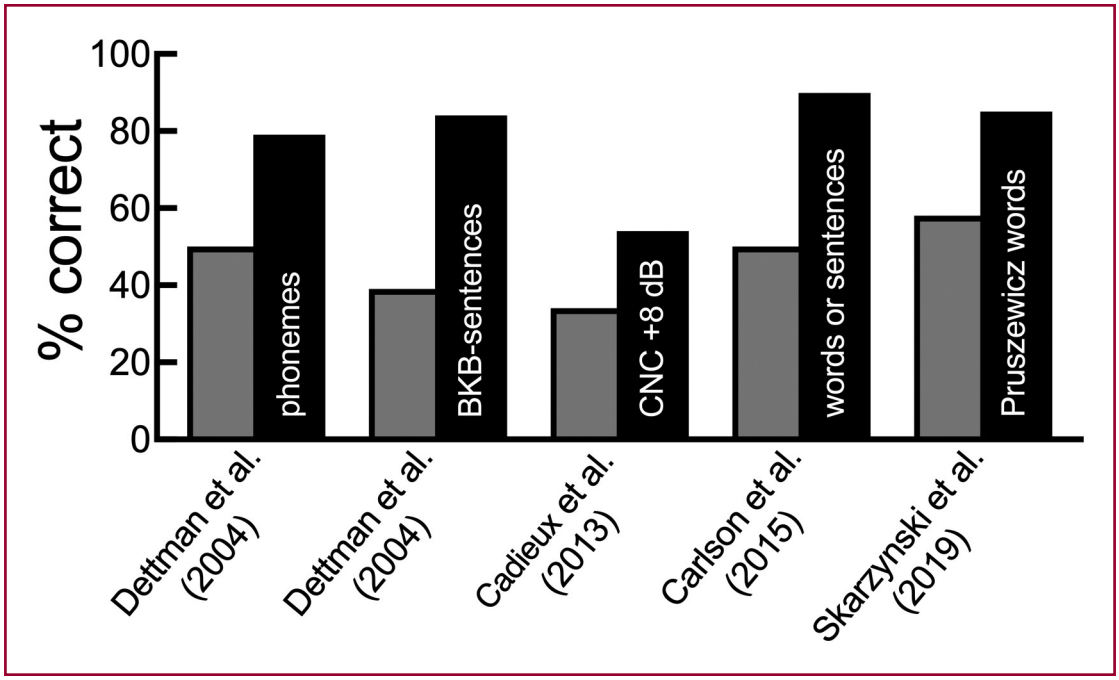


FIGURE 6–2. Pre- and postimplant speech recognition as presented in five studies demonstrating the efficacy of cochlear implantation for pediatric candidates with significant residual hearing and/or above criterion preoperative speech recognition. Gray and black bars represent pre- and postimplant scores, respectively. BKB Bamford-Kowal-Bench; CNC consonant nucleus consonant.

implanted would have met implant candidacy if an individual ear criterion were indicated.

In addition to the above-reference studies describing outcomes for nontraditional pediatric cochlear implant recipients, there are two large Australian studies providing data-driven guidance regarding expansion of audiometric criteria for pediatric cochlear implantation (Leigh, Dettman, & Dowell, 2016;. Leigh, Dettman, & Dowell, & Sarant, 2011). Leigh and colleagues (2011, 2016) evaluated speech recognition performance for 142 children and with hearing loss who were either fitted with hearing aids (n = 62) or cochlear implants [n = 80 (J. Leigh et al., 2011); n = 78 (Leigh et al., 2016). They found that for PTAs ≥65 dB HL, children have a 75% chance of improvement with a cochlear implant for word recognition as compared to bilateral hearing aids. Indeed, using this PTA-based criterion for pediatric candidate selection would be more consistent with current adult audiometric indications consistent with moderate-to-profound hearing loss. Using a more holistic approach to candidate selection, one could promote cochlear implantation for children with even less severe losses, provided that the child is failing to demonstrate year-for-year progress on measures speech, language, and auditory skills despite full-time use of hearing aids and adherence to the recommended speech/language therapy schedule (see also Chapter 3 and 4).

Infants Under 12 months of age

STUDENTS-HUB.com Uploaded By: tuka abuzneid

As stated in Chapters 1 and 3, current labeled indications for pediatric candidacy list children 12 months of age and older. This age restriction is not to imply that infants under 12 months would not benefit from cochlear implantation. Rather, there is a growing body of literature demonstrating significantly higher outcomes for children implanted under 12 months of age, even as compared to children implanted in the second year of life. These peer-reviewed reports of postoperative

outcomes for children implanted in the first year of life demonstrate significantly better outcomes on measures of word and language acquisition (Bergeson, Houston, & Miyamoto, 2010; Dettman et al., 2016; Houston, Beer, et al., 2012; Houston & Miyamoto, 2010; Houston, Stewart, Moberly, Hollich, & Miyamoto, 2012; Niparko et al., 2010; Tobey et al., 2013), speech perception (Dettman et al., 2016; Tajudeen, Waltzman, Jethanamest, & Svirsky, 2010), speech production or intelligibility (Habib, Waltzman, Tajudeen, & Svirsky, 2010), and vocabulary development (Dettman et al., 2016; Hayes, Geers, Treiman, & Moog, 2009; Houston & Miyamoto, 2010; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005).

One of the historical concerns about implanting infants under 12 months of age has been the issue of specificity—or the risk of implanting a child without permanent sensorineural hearing loss. With the audiologic tests at our disposal, including otoacoustic emissions, electrophysiologic measures, and advanced behavioral audiometric techniques for use in children as young as 5 to 6 months, initial diagnostic and then confirmatory diagnostic testing at very young ages is possible. Cosetti and Roland (2010) explain that there is a wealth of literature on the surgical and anesthetic-related risks associated with surgery in infants. Specifically, there is a higher incidence of morbidity, mortality, and life-threatening adverse surgical events for children under 12 months who undergo surgery; however, Cosetti and Roland (2010) explain that the majority of concerns and complications reported in the literature have been confounded by emergency surgery for which there has been a lack of fasting and hence greater risk of aspiration, as well as the risks of surgery in healthy children and possibly medically fragile infant (under 1 month of age). As related to cochlear implant surgery, there are a number of studies demonstrating no greater anesthetic risk for infants under 12 months (Colletti et al., 2005; Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; James & Papsin, 2004; McKinney, 2017; Miyamoto, Hay-McCutcheon, Kirk, Houston, & Bergeson-Dana, 2008; Miyamoto, Houston, & Bergeson, 2005; Valencia, Rimell, Friedman, Oblander, & Helmbrecht, 2008; Waltzman & Roland, 2005). There are surgical issues that are unique to infants under 12 months and those include intraoperative blood loss, facial nerve anatomy, skull thickness (<1 mm), fixation of the receiver/stimulator package, thin scalp flap, and device migration with skull growth (Cosetti & Roland, 2010). They reported, however, that these are known variables and can be mitigated with a highly trained surgical team having extensive pediatric experience.

Given the highly favorable risk/benefit ratio for implanting infants under 12 months, one might conclude that most children being identified at or near birth are routinely being implanted early. It is certainly the case that the request for insurance authorization is being submitted for infants as young as 6 to 9 months. The barrier to access for this population is that many insurance companies will often initially deny coverage citing that the FDA-labeled indications specify candidacy for children 12 months of age and older. There is a precedent for successful appeal particularly in peer-to-peer review when surgeons and audiologists are advocating for their patients; however, state Medicaid programs may deny authorization until a child reaches the 1-year mark. It may be the case that in the very near future a cost-utility study will promote cochlear implantation in children under 12 months given cost-saving measures (i.e., fewer hearing-related services) as the child ages.

UNILATERAL AND ASYMMETRICAL HEARING LOSSES

Implant candidacy has historically been based on speech recognition in the best-aided condition. To date, only one of the implant manufacturers has even made reference to considering preoperative performance in the ear to be implanted in their conventional implant labeled indications for adult candidates (Cochlear, 2019). The prevalence of asymmetric hearing loss among sensorineural losses is estimated at 50% to 57% (H. Liu et al., 2011; Margolis & Saly, 2008); hence, it is reasonable to presume that the "best-aided condition" may overestimate one's hearing and speech understanding, particularly for realistic listening environments in which the target stimulus may not always be

STUDENTS-HUB.com Uploaded By: tuka abuzneid

directed toward the front or the better-hearing ear. As mentioned in Chapters 2 and 3, the adult Minimum Speech Test Battery (MSTB, 2011) and PMSTB (Uhler, Warner-Czyz, Gifford, & Group, 2017) both recommend individual ear assessment of speech understanding performance.

Our current best practices guidance documents recommend individual ear assessment; thus we must question whether we should be determining implant candidacy solely on the basis of the ear to be implanted as opposed to the bilaterally aided condition. There is a growing literature base, including both adults and children with highly asymmetric hearing losses, as well as individuals with unilateral deafness—commonly referred to as single-sided deafness (SSD)—receiving cochlear implants in the poorer ear. Firszt and colleagues have described outcomes for adult (Firszt et al., 2012, 2018) and pediatric recipients (Cadieux et al., 2013) with asymmetric hearing loss for which implant candidacy was determined on the basis of the poorer-hearing ear. Even with the highly asymmetric nature of the hearing losses in their populations, the implant recipients demonstrated significant improvement in speech recognition performance in quiet and noise both in the implanted ear and in the bilateral aided condition (Cadieux et al., 2013; Firszt et al., 2012, 2018) as well as significantly improved localization (Firszt et al., 2012) as compared to preoperative performance. These findings suggest that we should consider implant candidacy on an individual-ear basis even when the better hearing ear exceeds traditional candidacy criteria.

SSD or Unilateral Hearing Loss

STUDENTS-HUB.com

Cochlear implantation for individuals with SSD has been a hot topic for at least the past decade. SSD is a special case of asymmetric hearing loss given that an individual has one ear with *clinically normal hearing*. This topic has garnered so much attention that there are scientific and clinical conferences dedicating entire sessions to cochlear implantation for SSD. There is even a multinational working group tasked with developing a uniform assessment protocol for this population (van de Heyning et al., 2016).

Though researchers have demonstrated that a single hearing ear is sufficient for a child to develop speech and language within the age normative range, children with SSD have been shown to exhibit greater fatigue, stress, and increased academic risk as compared to their normal-hearing peers (Bess, Dodd-Murphy, & Parker, 1998; Lieu, 2013, 2015; Lieu, Tye-Murray, & Fu, 2012; Lieu, Tye-Murray, Karzon, & Piccirillo, 2010; Rohlfs et al., 2017; Tharpe, 2008). In addition to fatigue, stress, and academic risk associated with SSD, there is concern about the currently approved interventions for this hearing loss, which include contralateral routing of sound (CROS) hearing aid systems, remote microphone systems (FM or DM systems), and bone anchored implants (BAIs). The primary concern with the use of CROS, FM, and BAI for SSD or asymmetric hearing losses, however, is that none of these interventions provide *binaural* information. The listener can only use these hearing technologies to deliver incoming sound to a single cochlea. Cochlear implantation is the only available intervention providing the listener with bilateral auditory input with the *possibility of binaural hearing restoration* (Dorman, Cook, Yost, Wanna, & Gifford, 2015; Zeitler et al., 2015). Based on the work of Gordon and colleagues, we would expect the long-term use of CROS, remote microphone systems, or BAIs to result in abnormal and asymmetric organization of the central auditory system (Gordon, Henkin, & Kral, 2015; Polonenko, Papsin, & Gordon, 2015, 2017).

As might be expected with an emerging indication, there is disagreement among professionals regarding the efficacy and ethics of cochlear implantation for adults and children with SSD. Much of the controversy originated from the fact that SSD was not an approved indication for cochlear implantation until July 2019 when MED-EL received FDA approval for SSD in individuals 5 years of age or older (see Chapter 1). Though there are a number of published studies, nearly all published data were either collected outside the U.S. or from within the U.S. in clinical trials, or from recipients in the U.S. who were implanted in an "off label" capacity. Indeed a systematic review of the SSD implant literature concluded that the relevant publications included "nonrandomized,

Uploaded By: tuka abuzneid

low or moderate level of evidence" (van Zon, Peters, Stegeman, Smit, & Grolman, 2015).

Though we have a great need for prospective, controlled studies with larger sample sizes, there are a number of peer-reviewed publications describing speech recognition, spatial hearing, and subjective reports following cochlear implantation in cases of SSD. Arndt et al. (2015) assessed speech understanding in co-located and spatially separated noise conditions in a group of 20 children with SSD (Arndt et al., 2015). They also obtained subjective reports of speech, spatial and qualitative reports prior to and following surgery using the SSQ questionnaire (Gatehouse & Noble, 2004) administered to the parents. They documented significant improvements in speech understanding with the use of the implant for conditions in which the noise was presented to the normal-hearing ear. They further reported significantly improved qualitative reports on all subscales of the SSQ following cochlear implantation. There are other reports of significant cochlear implant benefits for adults and children with SSD including (1) significant qualitative improvements in communication and quality of life (Arndt et al., 2017; Dillon et al., 2017; Finke, Bonitz, Lyxell, & Illg, 2017; Galvin et al., 2018; Mertens, Desmet, De Bodt, & van de Heyning, 2016), (2) spatial release from masking (Grossmann et al., 2016; Mertens, De Bodt, & van de Heyning, 2017; Prejban et al., 2018), and (3) horizontal plane localization (Doge, Baumann, Weissgerber, & Rader, 2017; Dorman et al., 2015; Galvin et al., 2018; Gartrell et al., 2014; Litovsky et al., 2019; Y. W. Liu et al., 2018; Mertens, Desmet, et al., 2016; Rahne & Plontke, 2016; Zeitler et al., 2015). Localization benefit is perhaps the most dramatic with improvement ranging from 20 to over 50 degrees of error. In many cases, cochlear implant recipients with SSD improve from chance performance with a single hearing ear to highly functional localization abilities. Thus cochlear implantation for individuals with SSD significantly improves spatial hearing abilities.

It is important to note that speech and qualitative outcomes tend to be better for implant recipients with postlingual onset deafness as well as an overall shorter duration of SSD, as compared to implant recipients with congenital losses and longer durations of SSD. Thus it may ultimately be the case that cochlear implantation is recommended for cases of SSD with short durations of deafness and/or postlingual onset. What is unknown at this time is whether or not the children with congenital SSD would have fared as well had they been implanted early in life minimizing the duration of unilateral auditory deprivation.

Other cases of cochlear implantation with asymmetric hearing loss and SSD have focused on tinnitus suppression rather than improving speech recognition. There are multiple reports of the benefits of cochlear implantation for patients with SSD as a means for tinnitus suppression (Amoodi et al., 2011; Arndt et al., 2011; Arts, George, Stokroos, & Vermeire, 2012; Buechner et al., 2010; Dillon et al., 2017; Finke et al., 2017; Gartrell et al., 2014; Kleinjung, Steffens, Strutz, & Langguth, 2009; Mertens, De Bodt, & van de Heyning, 2016; Punte et al., 2011; Ramos et al., 2012; van de Heyning et al., 2008; Vermeire & van de Heyning, 2009; Zeitler et al., 2019). Despite the increased interest in this topic in recent years, it remains unclear whether cochlear implantation for tinnitus suppression in cases of unilateral hearing loss is a cost efficient and viable treatment option and whether this is a treatment that will be ultimately covered by insurance per medical necessity.

PRELINGUALLY DEAFENED ADOLESCENTS AND ADULTS

When multichannel cochlear implants were first approved by the FDA for adults in 1985, the indications specified that candidates must have postlingual onset of hearing loss. The concern was that the auditory centers of the brain would be unable to make use of the new electric stimulus, and thus outcomes for speech understanding would be poor. Some of the pioneering researchers in the field published reports of relatively small samples of prelingually deafened adults who had received cochlear implants (Clark et al., 1987; Hinderink, Snik, Mens, Brokx, & Van den Broek, 1984; Skinner et al., 1992; Snik, Makhdoum, Vermeulen, Brokx, & van den Broek, 1997; Tong, Busby, & Clark, 1988; Waltzman & Cohen, 1999). These early studies confirmed predictions regarding poor outcomes with respect to open-set speech recognition. More recent reports questioning the efficacy of cochlear implantation for adults and

STUDENTS-HUB.com Uploaded By: tuka abuzneid

adolescent children with prelingual deafness have yielded mixed results with some showing significant, though reduced, benefit for open-set speech understanding (Caposecco, Hickson, & Pedley, 2012; Cusumano et al., 2017; Firszt et al., 2012; Gifford et al., 2018; Kaplan, Shipp, Chen, Ng, & Nedzelski, 2003; Klop, Briaire, Stiggelbout, & Frijns, 2007; Snik, Vermeulen, Geelen, Brokx, & van der Broek, 1997; Teoh, Pisoni, & Miyamoto, 2004) and others with significant improvement in auditory-only speech understanding (Dowell et al., 2002). Perhaps we should have a different set of expectations for postoperative outcomes with prelingually deafened adults and older children. The focus would be centered on improved quality of life, environmental sound awareness, safety, and overall psychosocial well-being. Prelingually deafened adults have consistently reported significant improvement in subjective benefit, satisfaction, and overall communication following cochlear implantation (Caposecco et al., 2012; Hiraumi, Yamamoto, Sakamoto, & J., 2010; Klop et al., 2007; Most, Shrem, & Duvdevani, 2010; van Dijkhuizen et al., 2011; Zwolan, Kileny, & Telian, 1996); thus, it is critical to acquire preoperative subjective estimates of hearing handicap, overall quality of life, and communication effectiveness in the prelingually deafened adult implant candidate. (See Chapter 2 for guidance on the availability of self-report measures that can be used for this purpose.)

In addition to the subjective measures recommended for determining implant candidate selection for adults with prelingual hearing loss, it is important to obtain preoperative estimates of speech understanding. Although the MSTB recommends the use of CNC words, AzBio sentences (in quiet and noise), and BKB-SIN sentence recognition in noise, we might want to consider the development of a supplemental or substitution test battery when assessing pre- and postimplant performance for adults with pre- and prelingual onset of deafness. At present, there are no standardized recommendations for such a modified battery. van Dijkhuizen and colleagues (2011) recommend a new test battery for the evaluation of prelingually deafened adults to serve as both a means of determining implant candidacy and for predicting postoperative speech-perception outcomes (van Dijkhuizen et al., 2011). The primary component of this proposed battery is the inclusion of speech production, or speech intelligibility, to be used as a predictive index of postoperative outcomes. Preimplant predictions about postimplant outcomes could aid expectations management, which is a vital component in preoperative counseling.

Another consideration relative to the pre and postimplant assessment of speech understanding for prelingually deafened patients is the inclusion of easier speech metrics, particularly for the assessment of sentence recognition. The AzBio sentence corpus, as included in the MSTB and PMSTB recommendations, includes two male and two female talkers who speak at a normal conversational rate. The AzBio sentences (Spahr et al., 2012) have an average of seven words per sentence and are consistent with a Flesch-Kincaid grade level of 3.9 (Flesch, 1948; Kincaid, Fishburne Jr, Rogers, & Chissom, 1975). By comparison, the HINT sentences (Nilsson, Soli, & Sullivan, 1994) include a single male talker who speaks at a slower rate using clear speech. The HINT sentences have an average of five words per sentence and are consistent with a Flesch-Kincaid grade level of 1.1 (Flesch, 1948; Kincaid et al., 1975). Using an easier sentence material, such as the HINT sentences, for the assessment of speech recognition for prelingually deafened adults may be a more appropriate measurement, particularly for tracking postoperative benefit. Another suggestion would be to place more emphasis on the accuracy of phoneme recognition for monosyllabic stimuli such as CNC words. Figure 6–3 displays a hypothetical battery of tests for use with prelingually deafened adults who have limited auditory skills. As discussed in Chapters 2 and 3, more than the protocol itself, what is essential is that all clinicians in a center follow the same practice. Protocol adherence allows each implant program to generate its own normative data for patient outcomes, which significantly aids patient counseling. This also provides clinicians with the data needed to compare their clinic's outcomes to average patient performance in the literature.

Just as we must be wary of ceiling effects in our assessment metrics, we must also be aware of floor effects. If we use the metrics recommended by the MSTB or PMSTB for our prelingual adult recipients, we should expect to see a high proportion

STUDENTS-HUB.com Uploaded By: tuka abuzneid

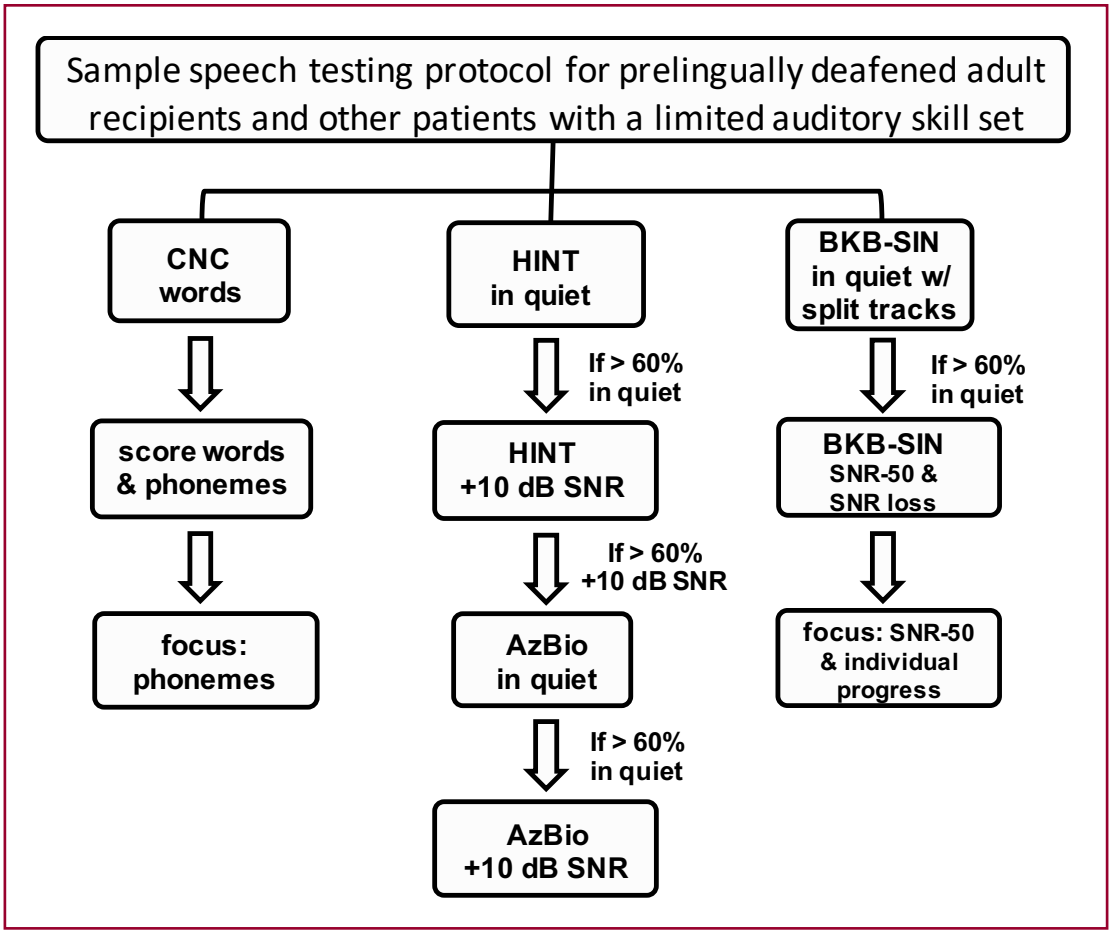


FIGURE 6–3. Sample speech-testing protocol for prelingually deafened adult recipients and other patients with a limited auditory skill set. CNC consonant nucleus consonant; HINT Hearing in Noise Test; BKB Bamford-Kowal-Bench; SNR signal-to-noise ratio.

of these patients scoring near 0%, possibly even in the postoperative condition. Floor effects render longitudinal tracking of patient progress nearly impossible. We should not patronize our patients with the use of such simple stimuli so as to misrepresent their progress; however, we do need to utilize the most appropriate measurement tools at our disposal. As clinicians, we must be prepared to challenge our patients in assessing progress, but also be sensitive to the fact that using metrics above the level of the patient's auditory skills will lead to frustration and discouragement. Just as we administer developmentally appropriate speech measures for our pediatric patients, the use of auditory-skill appropriate measures is sensible from a patient-management perspective. Should an individual center draft a testing protocol for patients with lower auditory skills, it is possible that over time the patient may demonstrate sufficient progress to a level at which the recommended MSTB can be used for assessment.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

COCHLEAR IMPLANTATION FOR CHILDREN WITH SPECIAL NEEDS: GLOBAL DEVELOPMENTAL DELAY

It is well known that up to 40% of children with sensorineural hearing loss also have other medical and/or developmental comorbidities including

cognitive, visual, motor, behavioral, and learning (Fortnum, Marshall, & Summerfield, 2002; Gallaudet Research Institute, 2008; Roberts & Hindley, 1999; Van Naarden, Decoufle, & Caldwell, 1999). Despite the prevalence of comorbidities in childhood hearing loss, there is currently no professional consensus regarding cochlear implantation as a viable, successful treatment option for children with special needs, particularly for those children with compromised cognition and severe global developmental delay.

An obvious, nontrivial consideration in determining cochlear implant candidacy for children with hearing loss and special needs is the difficulty in obtaining reliable behavioral estimates of hearing. In some cases, we may not be able to obtain reliable behavioral audiometric thresholds; however, given the various objective measures of auditory function we have at our disposal, confirmation of the nature and degree of hearing loss for even the nonresponsive child is possible. Furthermore, sedated magnetic resonance imaging (MRI) can confirm the presence and structural status of the auditory nerve.

Expectations management is a vital component of preimplant counseling for families. There will be those families believing that the restoration of hearing will resolve impaired cognition, behavioral issues, autism, and so forth. Hearing loss certainly complicates these diagnoses by restricting effective communication. Indeed, significant hearing loss confounds the interpretation of neurodevelopmental assessment, and thus it is possible to observe significant improvement in a child's behavior and overall responsiveness following cochlear implantation; however, in most cases, hearing loss is not the underlying cause of the developmental delay. This is particularly true for diagnoses including, but not limited to, agenesis of the corpus callosum, autism, cerebral palsy, Down syndrome, Fragile X syndrome, and Rett syndrome. Thus, it is critical that we have the counseling skills needed to be empathetic as well as honest and realistic about what cochlear implants can and cannot do in this special population (Figure 6–4).

A recurrent theme throughout this chapter has been determining implant selection on an individual patient basis. Perhaps no other situation dictates the individuality of candidate selection and assessment more than that for children with special needs. We generally expect more modest outcomes with respect to the development of auditory skills and auditory/oral speech and language, particularly for those children exhibiting significant global developmental delay. In many reports, children with developmental delay

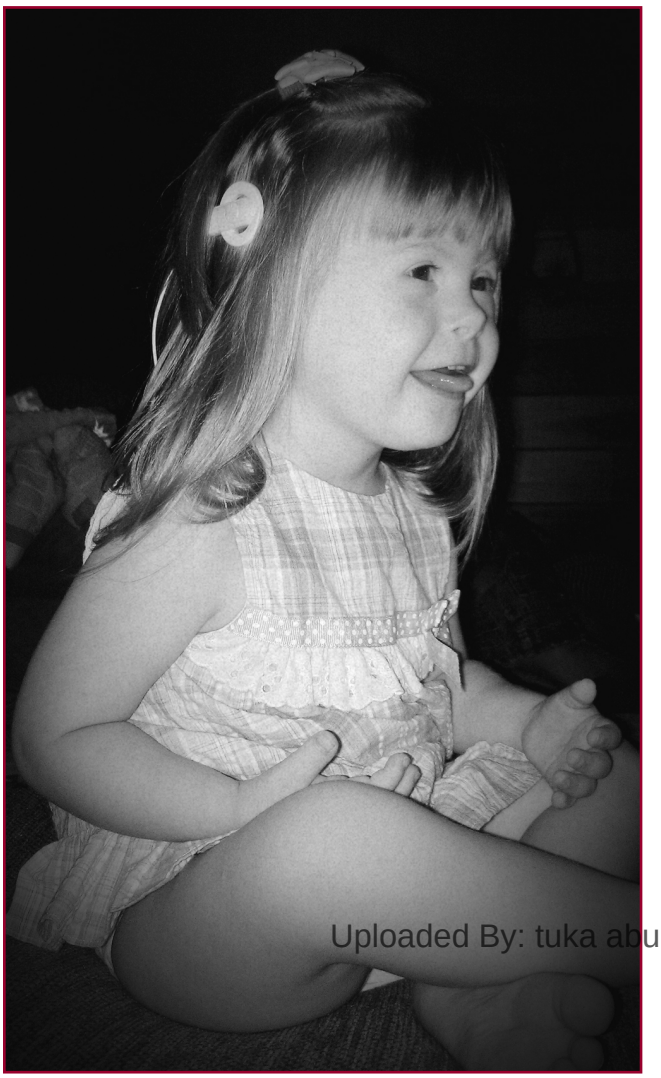


FIGURE 6–4. Savanna is an adorable 4-year-old bilateral implant recipient with Down syndrome. Savanna's mother reported that her speech, language, and overall motoric development dramatically improved following activation of her first implant at nearly 2 years of age. Savanna loves to sing and is able to do so as a result of her implants.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

demonstrated significant postoperative benefit in auditory perceptual skills (Bruce, Broomfield, Henderson, Green, & Ramsden, 2011; Hamzavi et al., 2000; Meinzen-Derr, Wiley, Grether, & Choo, 2011; Pyman, Blamey, Lacy, Clark, & Dowell, 2000; Steven et al., 2011; Waltzman, Scalchunes, & Cohen, 2000) and overall quality of life for the child and his or her family. Although our definition of what constitutes "successful outcome" will be individually tailored for each child, the presence of global developmental delay should not preclude cochlear implantation (Figure 6–4).

COCHLEAR IMPLANTATION FOR PATIENTS WITH NEUROFIBROMATOSIS TYPE 2

Neurofibromatosis type 2 (NF2) is an autosomal dominant genetic disorder that results in the development of various nonmalignant tumors along nerves and structures within the central nervous system. Individuals with NF2 generally develop bilateral vestibular schwannomas (more commonly referred to as acoustic neuromas), which over time lead to bilateral profound deafness. Historically, aural rehabilitation for patients with NF2 has included conventional amplification until the point at which surgical removal of the tumor(s) is required. For large and invasive tumors, an auditory brainstem implant (ABI) is generally placed during neuro-otologic surgery for tumor resection. Patients with ABIs, however, typically exhibit modest postoperative speech recognition in the absence of visual cues (Behr et al., 2014; Colletti & Shannon, 2005; Goffi-Gomez et al., 2012; Kuchta, 2007; Peng, Lorenz, Otto, Brackmann, & Wilkinson, 2018; Siegbahn et al., 2014; Wong et al., 2019), with many recipients never achieving open-set speech understanding.

There have been a number of reports describing successful cochlear implantation following treatment either via stereotactic radiosurgery (gamma knife) or surgical resection with neural preservation (Ahsan, Telischi, Hodges, & Balkany, 2003; Aristegui & Denia, 2005; Carlson et al., 2012; Graham et al., 1999; Harris et al., 2017; Hoffman, Kohan, & Cohen, 1992; Lustig et al., 2006; Neff et al., 2007; Nolle et al., 2003; Peng et al., 2018; Roehm et al., 2011; Temple et al., 1999; Tono, Ushisako, & Morimitsu, 1996; Tran Ba Huy, Kania, Frachet, Poncet, & Legac, 2009; Trotter & Briggs, 2010; Vincenti, Pasanisi, Guida, Di Trapani, & Sanna, 2008). Outcomes for speech understanding can be quite variable in this population, though scores are generally much higher with a greater proportion of patients achieving open-set speech recognition than reported following ABI placement. It has been hypothesized that poorer than typical word recognition outcomes are the result of the electric signal being transmitted across a diseased neural system, which is not the case for the conventional cochlear implant recipient with cochlear hearing loss.

Recommendations of cochlear implantation in cases of NF2 should be accompanied with considerable patient counseling regarding outcomes and expectations. A well-known and expected scenario is that additional tumors develop along the auditory pathway; thus, it is possible that even with neural preservation following tumor resection, disease progression may ultimately restrict or completely terminate reliable function of the implant.

CONCLUSION

Clinical practice has dramatically evolved over the past several decades, and cochlear implants are now recognized as a viable and effective treatment option for individuals with less severe losses who are exhibiting communication difficulty with appropriately fitted hearing aids. A number of studies have demonstrated the efficacy of cochlear implants for individuals falling outside labeled indications with respect to audiometric thresholds (severity, configuration, and symmetry), speech understanding, age, etiology, and developmental abilities. As stressed throughout Chapters 2 and 3, it is of critical importance that implant candidate selection be determined on an individual basis considering the whole patient—rather than focusing entirely on the audiogram. Although indications are in place to provide guid-

STUDENTS-HUB.com Uploaded By: tuka abuzneid

ance for clinicians and patients, there will never be a substitute for the professional clinical judgment of the clinician and the interdisciplinary cochlear implant team.

REFERENCES

Adunka, O., Buss, E., Clark, M., Pillsbury, H. C., & Buchman, C. A. (2008). Effect of preoperative residual hearing on speech perception after cochlear implantation. *Laryngoscope*, *118*, 2044–2049.

Ahsan, S., Telischi, F., Hodges, A., & Balkany, T. (2003). Cochlear implantation concurrent with translabyrinthine acoustic neuroma resection. *Laryngoscope*, *113*, 472–474.

Amoodi, H. A., Mick, P. T., Shipp, D. B., Friesen, L. M., Nedzelski, J. M., Chen, J. M., & Lin, V. Y. (2011). The effects of unilateral cochlear implantation on the tinnitus handicap inventory and the influence on quality of life. *The Laryngoscope*, *121*(7), 1536–1540.

Aristegui, M., & Denia, A. (2005). Simultaneous cochlear implantation and translabyrinthine removal of vestibular schwannoma in an only hearing ear: Report of two cases (neurofibromatosis type 2 and unilateral vestibular schwannoma). *Otology & Neurotology*, *26*, 205–210.

Arndt, S., Aschendorff, A., Laszig, R., Beck, R., Schild, C., Kroeger, S., . . . Wesarg, T. (2011). Comparison of pseudobinaural hearing to real binaural hearing rehabilitation after cochlear implantation in patients with unilateral deafness and tinnitus. *Otology & Neurotology*, *32*(1), 39–47. https://doi.org/10.1097/MAO.0b013e3181fcf271

Arndt, S., Laszig, R., Aschendorff, A., Hassepass, F., Beck, R., & Wesarg, T. (2017). Cochlear implant treatment of patients with single-sided deafness or asymmetric hearing loss. *HNO*, *65*(Suppl 2), 98–108.

Arndt, S., Prosse, S., Laszig, R., Wesarg, T., Aschendorff, A., & Hassepass, F. (2015). Cochlear implantation in children with single-sided deafness: Does aetiology and duration of deafness matter? *Audiology and Neuro-Otology*, *20*(Suppl. 1), 21–30.

Arts, R. A., George, E. L., Stokroos, R. J., & Vermeire, K. (2012). Review: cochlear implants as a treatment of tinnitus in single-sided deafness. *Current Opinion in Otolaryngology & Head and Neck Surgery*, *20*(5), 398–403.

Behr, R., Colletti, V., Matthies, C., Morita, A., Nakatomi, H., Dominique, L., . . . Skarzynski, H. (2014). New outcomes with auditory brainstem implants in NF2 patients. *Otology & Neurotology*, *35*(10), 1844–1851.

Beijen, J. W., Mylanus, E. A., Leeuw, A. R., & Snik, A. F. (2008). Should a hearing aid in the contralateral ear be recommended for children with a unilateral cochlear implant? *Annals of Otology, Rhinology and Laryngology*, *117*(6), 397–403.

Berchick, E. R., Hood, E., & Barnett, J. C. (2018). *Health Insurance Coverage in the United States: 2017*. Retrieved from https://www.census.gov/content/dam/Census/library/publications/2018/demo/p60-264.pdf

Bergeson, T. R., Houston, D. M., & Miyamoto, R. T. (2010). Effects of congenital hearing loss and cochlear implantation on audiovisual speech perception in infants and children. *Restorative Neurology and Neuroscience*, *28*, 157–165.

Bess, F. H., Dodd-Murphy, J., & Parker, R. A. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear and Hearing*, *19*(5), 339–354.

Bradham, T., & Jones, G. (2008). Cochlear implant candidacy in the United States: Prevalence in children 12 months to 6 years of age. *International Journal of Pediatric Otorhinolaryngology*, *72*, 1023–1028.

Brown, R. F., Hullar, T. E., Cadieux, J. H., & Chole, R. A. (2010). Residual hearing preservation after pediatric cochlear implantation. *Otology & Neurotology*, *31*(8), 1221.

Bruce, I. A., Broomfield, S. J., Henderson, L., Green, K. M., & Ramsden, R. T. (2011). Cochlear implantation in Donnai-Barrow syndrome. *Cochlear Implants International*, *12*(1), 60–63.

Bruce, I. A., Felton, M., Lockley, M., Melling, C., Lloyd, S. K., Freeman, S. R., & Green, K. M. (2014). Hearing preservation cochlear implantation in adolescents. *Otology & Neurotology*, *35*(9), 1552–1559.

Buechner, A., Brendel, M., Lesinski-Schiedat, A., Wenzel, G., Frohne-Buechner, C., Jaeger, B., & Lenarz, T. (2010). Cochlear implantation in unilateral deaf subjects associated with ipsilateral tinnitus. *Otology & Neurotology*, *31*(9), 1381–1385.

Cadieux, J. H., Firszt, J. B., & Reeder, R. M. (2013). Cochlear implantation in nontraditional candidates: Preliminary results in adolescents with asymmetric hearing loss. *Otology & Neurotology*, *34*, 408–415.

Caposecco, A., Hickson, L., & Pedley, K. (2012). Cochlear implant outcomes in adults and adolescents with early-onset hearing loss. *Ear and Hearing*, *33*(2), 209–220.

Carlson, M. L., Breen, J. T., Driscoll, C. L., Link, M. J., Neff, B. A., Gifford, R. H., & Beatty, C. W. (2012). Cochlear implantation in patients with neurofibromatosis

STUDENTS-HUB.com Uploaded By: tuka abuzneid

type 2: Variables affecting auditory performance. *Otology and Neurotology*, *33*(5), https://doi.org/10.1097/MAO.0b013e318254fba5

Carlson, M. L., Patel, N. S., Tombers, N. M., DeJong, M. D., Breneman, A. I., Neff, B. A., & Driscoll, C. L. W. (2017). Hearing preservation in pediatric cochlear implantation. *Otology & Neurotology*, *38*(6), e128–133.

Carlson, M. L., Sladen, D. P., Haynes, D. S., Driscoll, C. L., DeJong, M. D., Erickson, H. C., . . . Gifford, R. H. (2014). Evidence for the expansion of pediatric cochlear implant candidacy. *Otology and Neurotology*, 36(1), 43–50 https://doi.org/10.1097/MAO.0000000000000607

Cheng, X., Liu, Y., Wang, B., Yuan, Y., Galvin, J. J., Fu, Q. J., . . . Chen, B. (2018). The benefits of residual hair cell function for speech and music perception in pediatric bimodal cochlear implant listeners. *Neural Plasticity*, *15*, 4610592. https://doi.org/10.1155/2018/4610592

Ching, T. Y., Hill, M., Brew, J., Incerti, P., Priolo, S., Rushbrook, E., & Forsythe, L. (2005). The effect of auditory experience on speech perception, localization, and functional performance of children who use a cochlear implant and a hearing aid in opposite ears. *International Journal of Audiology*, *44*(12), 677–690.

Ching, T. Y., Incerti, P., Hill, M., & van Wanrooy, E. (2006). An overview of binaural advantages for children and adults who use binaural/bimodal hearing devices. *Audiology and Neurotology*, *11*(Suppl. 1), 6–11.

Ching, T. Y., Psarros, C., Hill, M., Dillon, H., & Incerti, P. (2001). Should children who use cochlear implants wear hearing aids in the opposite ear? *Ear and Hearing*, *22*, 365–380.

Choi, J. E., Moon, I. J., Kim, E. Y., Park, H. S., Kim, B. K., Chung, W. H., . . . Hong, S. H. (2017). Sound localization and speech perception in noise of pediatric cochlear implant recipients: Bimodal fitting versus bilateral vochlear implants. *Ear and Hearing*, *38*(4), 426–440.

Clark, G. M., Busby, P. A., Roberts, S. A., Dowell, R. C., Blamey, P. J., Mecklenburg, D. J., & Franz, B. K. (1987). Preliminary results for the cochlear corporation multielectrode intracochlear implant in six prelingually deaf patients. *American Journal of Otology*, *8*, 234–239.

Cochlear. (2019). Nucleus cochlear implants: hysician's package insert.

Cohen, S. M., Labadie, R. F., & Haynes, D. S. (2005). Primary care approach to hearing loss: The hidden disability. *Ear Nose and Throat Journal*, *84*(1), 29–31.

Colletti, V., Carner, M., Miorelli, V., Guida, M., Colletti, L., & Fiorino, F. G. (2005). Cochlear implantation at under 12 months: Report on 10 patients. *Laryngoscope*, *115*, 445–449.

Colletti, V., & Shannon, R. V. (2005). Open set speech perception with auditory brainstem implant? *Laryngoscope*, *115*(11), 1974–1978.

Cosetti, M., & Roland, J. T. (2010). Cochlear implantation in the very young child: Issues unique to the under-1 population. *Trends in Amplification*, *14*, 46–57.

Cowan, R. S., DelDot, J., Barker, J. Z., Barker, E. J., Sarant, J. Z., Pegg, P., & Dowell, R. C. (1997). Speech perception results for children with implants with different levels of preoperative residual hearing. *American Journal of Otology*, *18*(Suppl. 6), S125–S126.

Cusumano, C., Friedmann, D. R., Fang, Y., Wang, B., Roland, J. T., & Waltzman, S. B. (2017). Performance plateau in prelingually and postlingually deafened adult cochlear implant recipients. *Otology & Neurotology*, *38*(3), 334–338.

Dettman, S. J., Dowell, R. C., Choo, D., Arnott, W., Abrahams, Y., Davis, A., . . . Briggs, R. J. (2016). Long-term communication outcomes for children receiving cochlear implants younger than 12 months. *Otology & Neurotology*, *37*(2), e82–e95.

Dettman, S. J., D'Costa, W. A., Dowell, R. C., Winton, E. J., Hill, K. L., & Williams, S. S. (2004). Cochlear implants for children with significant residual hearing. *Archives of Otolaryngology-Head and Neck Surgery*, *130*, 612–618.

Dettman, S. J., Pinder, D., Briggs, R. J., Dowell, R. C., & Leigh, J. R. (2007). Communication development in children who receive the cochlear implant younger than 12 months: Risks versus benefits. *Ear and Hearing*, *28*, 11S–18S.

Dillon, M. T., Buss, E., Rooth, M. A., King, E. R., Deres, E. J., Buchman, C. A., . . . Brown, K. D. (2017). Effect of cochlear implantation on quality of life in adults with unilateral hearing loss. *Audiology and Neuro-Otology*, *22*(4–5), 259–271.

Doge, J., Baumann, U., Weissgerber, T., & Rader, T. (2017). Single-sided deafness: Impact of cochlear implantation on speech perception in complex noise and on auditory localization accuracy. *Otology & Neurotology*, *38*(10), e563–e569.

Dorman, M. F., Cook, S. J., Yost, W. A., Wanna, B., & Gifford, R. H. (2015). Interaural level difference cues determine sound source localization by single-sided deaf patients fit with a cochlear implant. 183–188. https://doi.org/10.1159/000375394

Dorman, M., Zeitler, D., Cook, S. J., Loiselle, L., Yost, W. A., Wanna, G. B., & Gifford, R. H. (2015). Interaural level difference cues determine sound source

STUDENTS-HUB.com Uploaded By: tuka abuzneid

localization by single-sided deaf patients fit with a cochlear implant. *Audiology and Neurotology*, *20*(3). https://doi.org/10.1159/000375394

Dowell, R. C., Dettman, S. J., Hill, K., Winton, E., Barker, E. J., & Clark, G. M. (2002). Speech perception outcomes in older children who use multichannel cochlear implants: Older is not always poorer. *Annals of Otology, Rhinology and Laryngology Supplment*, *189*, 97–101.

Eisenberg, L. S., Martinez, A. S., Holowecky, S. R., & Pogorelsky, S. (2002). Recognition of lexically controlled words and sentences by children with normal hearing and children with cochlear implants. *Ear and Hearing*, *23*(5), 450–462.

Finke, M., Bonitz, H., Lyxell, B., & Illg, A. (2017). Cochlear implant effectiveness in postlingual single-sided deaf individuals: What's the point? *International Journal of Audiology*, *56*(6), 417–423.

Firszt, J. B., Holden, L. K., Reeder, R. M., Cowdrey, L., & King, S. (2012). Cochlear implantation in adults with asymmetric hearing loss. *Ear and Hearing*, *33*(4), 521–533.

Firszt, J. B., Reeder, R. M., Holden, L. K., & Dwyer, N. Y. (2018). Results in adult cochlear implant recipients with varied asymmetric hearing: A prospective longitudinal study of speech recognition, localization, and participant report. *Ear & Hearing*, *39*, 845–862.

Flesch, R. (1948). A new readability yardstick. *Journal of Applied Psychology*, *32*, 221–233.

Fortnum, H. M., Marshall, D. H., & Summerfield, A. Q. (2002). Epidemiology of the UK population of hearing-impaired children, including characteristics of those with and without cochlear implants—audiology, aetiology, comorbidity and affluence. *International Journal of Audiology*, *4*, 170–179.

Gallaudet Research Institute. (2008). *Regional and national summary report of data from the 2008 annual survey of deaf and hard of hearing children and youth*. Washington, DC.

Galvin, J. J., Fu, Q. J., Wilkinson, E. P., Mills, D., Hagan, S. C., Lupo, J. E., . . . Shannon, R. V. (2018). Benefits of cochlear implantation for single-sided deafness: Data from the House Clinic-University of Southern California-University of California, Los Angeles Clinical Trial. *Ear and Hearing*, *2018 Oct 2*, epub ahead of print.

Gantz, B. J., Rubinstein, J. T., Tyler, R. S., Teagle, H. F., Cohen, N. L., Waltzman, S. B., & Kirk, K. I. (2000). Long-term results of cochlear implants in children with residual hearing. *Annals of Otology, Rhinology, and Laryngology Supplement*, *185*, 33–36.

Gartrell, B. C., Jones, H. G., Kan, A., Buhr-Lawler, M., Gubbels, S. P., & Litovsky, R. Y. (2014). Investigating long-term effects of cochlear implantation in single-sided deafness: A best practice model for longitudinal assessment of spatial hearing abilities and tinnitus handicap. *Otology & Neurotology*, *35*(9), 1525–1532.

Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*, *43*(2), 85–99.

Gifford, R. H., Dorman, M. F., Shallop, J. K., & Sydlowski, S. A. (2010). Evidence for the expansion of adult cochlear implant candidacy. *Ear and Hearing*, *31*(2). https://doi.org/10.1097/AUD.0b013e3181c6b831

Gifford, R. H., Noble, J. H., Camarata, S. M., Sunderhaus, L. W., Dwyer, R. T., Dawant, B. M., . . . Labadie, R. F. (2018). The relationship between spectral modulation detection and speech recognition: adult versus pediatric cochlear implant recipients. *Trends in Hearing*, *22*, 1–15.

Goffi-Gomez, M. V., Magalhães, A. T., Brito Neto, R., Tsuji, R. K., Gomes Mde, Q., & Bento, R. F. (2012). Auditory brainstem implant outcomes and MAP parameters: Report of experiences in adults and children. *International Journal of Pediatric Otorhinolaryngology*, *76*(2), 257–264.

Goman, A. M., & Lin, F. R. (2016). Prevalence of hearing loss by severity in the United States. *American Journal of Public Health*, *106*(10), 1820–1822.

Gordon, K., Henkin, Y., & Kral, A. (2015). Asymmetric hearing during development: The aural preference syndrome and treatment options. *Pediatrics*, *136*(1), 141–153. https://doi.org/10.1542/peds.2014-3520

Graham, J., Lynch, C., Weber, B., Stollwerck, L., Wei, J., & Brookes, G. (1999). The magnetless Clarion cochlear implant in a patient with neurofibromatosis 2. *Journal of Laryngology & Otology*, *113*, 458–463.

Grossmann, W., Brill, S., Moeltner, A., Mlynski, R., Hagen, R., & Radeloff, A. (2016). Cochlear implantation improves spatial release from masking and restores localization abilities in single-sided deaf patients. *Otology & Neurotology*, *37*(6), 658–664.

Habib, M. G., Waltzman, S. B., Tajudeen, B., & Svirsky, M. A. (2010). Speech production intelligibility of early implanted pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology*, *74*(8), 855–859. https://doi.org/10.1016/j.ijporl.2010.04.009

Hamzavi, J., Baumgartner, W. D., Egelierler, B., Franz, P., Schenk, B., & Gstoettner, W. (2000). Follow-up of cochlear implanted handicapped children. *Inter-*

STUDENTS-HUB.com Uploaded By: luka abuzneid

national Journal of Pediatric Otorhinolaryngology, *56*, 169–174.

Harris, F., Tysome, J. R., Donnelly, N., Durie-Gair, J., Crundwell, G., Tam, Y. C., . . . Axon, P. (2017). Cochlear implants in the management of hearing loss in neurofibromatosis type 2. *Cochlear Implants International*, *18*(3), 171–179.

Hayes, H., Geers, A. E., Treiman, R., & Moog, J. S. (2009). Receptive vocabulary development in deaf children with cochlear implants: achievement in an intensive auditory-oral educational setting. *Ear and Hearing*, *30*(1), 128–135. https://doi.org/10.1097/AUD.0b013e3181926524

Hinderink, J. B., Snik, A. F., Mens, L. H., Brokx, J. P., & Van den Broek, P. (1984). Performance of prelingually or postlingually deafened adults who were using a single or multichannel cochlear implant. *Ear, Nose & Throat Journal*, *73*(3), 180–183.

Hiraumi, H., Yamamoto, N., Sakamoto, T., & J., I. (2010). Cochlear implantation in patients with prelingual hearing loss. *Acta Otolaryngologica Supplement*, *563*, 4–10.

Hoffman, R. A., Kohan, D., & Cohen, N. L. (1992). Cochlear implants in the management of bilateral acoustic neuromas. *American Journal of Otology*, *13*, 525–528.

Holt, R. F., Kirk, K. I., Eisenberg, L. S., Martinez, A. S., & Campbell, W. (2005). Spoken word recognition development in children with residual hearing using cochlear implants and hearing aids in opposite ears. *Ear and Hearing*, *26*(4 Suppl.), 82S–91S.

Houston, D. M., Beer, J., Bergeson, T. R., Chin, S. B., Pisoni, D. B., & Miyamoto, R. T. (2012). The ear is connected to the brain: some new directions in the study of children with cochlear implants at Indiana University. *Journal of the American Academy of Audiology*, *23*(6), 446–463. https://doi.org/10.3766/jaaa.23.6.7

Houston, D. M., & Miyamoto, R. T. (2010). Effects of early auditory experience on word learning and speech perception in deaf children with cochlear implants: Implications for sensitive periods of language development. *Otology & Neurotology*, *31*, 1248–1253.

Houston, D. M., Stewart, J., Moberly, A., Hollich, G., & Miyamoto, R. T. (2012). Word learning in deaf children with cochlear implants: Effects of early auditory experience. *Developmental Science*, *15*, 448–461.

Huart, S., & Sammeth, C. (2009). Identifying cochlear implant candidates in the hearing aid dispensing practice. *Hearing Review*, *16*(5), 24–32.

James, A. L., & Papsin, B. C. (2004). Cochlear implant surgery at 12 months of age or younger. *Laryngoscope*, *114*, 2191–2195.

Kaplan, D. M., Shipp, D. B., Chen, J. M., Ng, A. H., & Nedzelski, J. M. (2003). Early-deafened adult cochlear implant users: Assessment of outcomes. *Journal of Otolaryngology*, *32*(4), 245–249.

Ketterer, M. C., Knopke, S., Haubler, S. M., Hildenbrand, T., Becker, C., Grabel, S., & Olze, H. (2018). Asymmetric hearing loss and the benefit of cochlear implantation regarding speech perception, tinnitus burden and psychological comorbidities: A prospective follow-up study. *European Archives of Oto-Rhino-Laryngology*, *275*(11), 2683–2693.

Kincaid, J. P., Fishburne Jr, R. P., Rogers, R. L., & Chissom, B. S. (1975). Derivation of new readability formulas (Automated Readability Index, Fog Count and Flesch Reading Ease Formula) for navy enlisted personnel.

Kleinjung, T., Steffens, T., Strutz, J., & Langguth, B. (2009). Curing tinnitus with a cochlear implant in a patient with unilateral sudden deafness: A case report. *Cases Journal*, *18*(2), 7462.

Klop, W. M., Briaire, J. J., Stiggelbout, A. M., & Frijns, J. H. (2007). Cochlear implant outcomes and quality of life in adults with prelingual deafness. *Laryngoscope*, *117*(11), 1982–1987.

Kuchta, J. (2007). Twenty-five years of auditory brainstem implants: Perspectives. *Acta Neurochirurgica Supplement*, *97*(Pt. 2), 443–449.

Leigh, J. R., Dettman, S. J., & Dowell, R. C. (2016). Evidence-based guidelines for recommending cochlear implantation for young children: Audiological criteria and optimizing age at implantation. *International Journal of Audiology*, *55* (Suppl. 2), S9–S18. https://doi.org/10.3109/14992027.2016.1157268

Leigh, J., Dettman, S., Dowell, R. C., & Sarant, J. (2011). Evidence-based approach for making cochlear implant recommendations for infants with residual hearing. *Ear and Hearing*, *32*, 313–322.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Lieu, J. E. (2013). Unilateral hearing loss in children: speech-language and school performance. *B-ENT*, (Suppl. 21), 107–115.

Lieu, J. E. (2015). Management of children with unilateral hearing loss. *Otolaryngologic Clinics of North America*, *48*(6), 1011–1026.

Lieu, J. E., Tye-Murray, N., & Fu, Q. J. (2012). Longitudinal study of children with unilateral hearing loss. *Laryngoscope*, *22*, 2088–2095.

Lieu, J. E., Tye-Murray, N., Karzon, R. K., & Piccirillo, J. F. (2010). Unilateral hearing loss is associated with

worse speech-language scores in children. *Pediatrics*, *125*, e1348–e1355.

Litovsky, R. Y., Moua, K., Godar, S., Kan, A., Misurelli, S. M., & Lee, D. J. (2019). Restoration of spatial hearing in adult cochlear implant users with single-sided deafness. *Hearing Research*, *372*, 69–79.

Liu, H., Zhang, H., Bentler, R. A., Mo, L., Han, D., & Zhang, L. (2011). Audiometric records analysis in a clinical population in China. *ORL Journal for Otorhinolaryngology and Its Related Specialties*, *73*(5), 237–245.

Liu, Y. W., Cheng, X., Chen, B., Peng, K., Ishiyama, A., & Fu, Q. J. (2018). Effect of tinnitus and duration of deafness on sound localization and speech recognition in noise in patients with single-sided seafness. *Trends in Hearing*, *22*(Jan–Dec), 2331216518813802. https://doi.org/10.1177/2331216518813802

Lustig, L. R., Yeagle, J., Driscoll, C. L., Blevins, N., Francis, H., & Niparko, J. K. (2006). Cochlear implantation in patients with neurofibromatosis type 2 and bilateral vestibular schwannoma. *Otology & Neurotology*, *27*, 512–518.

Manjaly, J. G., Nash, R., Ellis, W., Britz, A., Lavy, J. A., Shaida, A., . . . Khalil, S. S. (2018). Hearing preservation with standard length electrodes in pediatric cochlear implantation. *Otology & Neurotology*, *39*(9), 1109–1114.

Margolis, R. H., & Saly, G. L. (2008). Asymmetric hearing loss: Definition, validation, and prevalence. *Otology & Neurotology*, *29*(4), 422–431.

McKinney, S. (2017). Cochlear implantation in children under 12 months of age. *Current Opinion in Otolaryngology & Head and Neck Surgery*, *25*(5), 400–404.

Mehra, S., Eavey, R. D., & Keamy, D. G. J. (2009). The epidemiology of hearing impairment in the United States. *Otolaryngology-Head and Neck Surgery*, *140*(4), 461–472.

Meinzen-Derr, J., Wiley, S., Grether, S., & Choo, D. I. (2011). Children with cochlear implants and developmental disabilities: A language skills study with developmentally matched hearing peers. *Research in Developmental Disabilities*, *32*, 757–767.

Menapace, C. M. (2019). *Personal communication*. Centennial, CO: Cochlear Ltd.

Mertens, G., De Bodt, M., & van de Heyning, P. (2016). Cochlear implantation as a long-term treatment for ipsilateral incapacitating tinnitus in subjects with unilateral hearing loss up to 10 years. *Hearing Research*, *331*, 1–6.

Mertens, G., Desmet, J., De Bodt, M., & van de Heyning, P. (2016). Prospective case-controlled sound localisation study after cochlear implantation in adults with single-sided deafness and ipsilateral tinnitus. *Clinical Otolaryngology*, *41*(5), 511–518.

Mertens, G., De Bodt, M., & van de Heyning, P. (2017). Evaluation of long-term cochlear implant use in subjects with acquired unilateral profound hearing loss: Focus on binaural auditory outcomes. *Ear and Hearing2*, *38*(1), 117–125.

Miyamoto, R. T., Hay-McCutcheon, M. J., Kirk, K. I., Houston, D. M., & Bergeson-Dana, T. (2008). Language skills of profoundly deaf children who received cochlear implants under 12 months of age: A preliminary study. *Acta Oto-Laryngologica*, *128*, 373–377.

Miyamoto, R. T., Houston, D. M., & Bergeson, T. (2005). Cochlear implantation in deaf infants. *Laryngoscope*, *115*, 1376–1380.

Mok, M., Galvin, K. L., Dowell, R. C., & McKay, C. M. (2010). Speech perception benefit for children with a cochlear implant and a hearing aid in opposite ears and children with bilateral cochlear implants. *Audiology and Neurotology*, *15*(1), 44–56.

Mondaine, M., Sillon, M., Vieu, A., Levi, A., Reuilard-Artieres, F., & Deguine, O. (2002). Cochlear implantation in prelingually deafened children with residual hearing. *International Journal of Pediatric Otorhinolaryngology*, *63*, 91–97.

Most, T., Shrem, H., & Duvdevani, I. (2010). Cochlear implantation in late-implanted adults with prelingual deafness. *American Journal of Otolaryngology*, *31*(6), 418–423.

Mudrey, J. A., Francis, R., McCrary, H., & Jacob, A. (2017). Older individuals meeting Medicare cochlear implant candidacy criteria in noise but not in quiet: Are these patients improved by surgery? *Otology & Neurotology, 38*(2), 187–191.

Neff, B. A., Wiet, R. M., Lasak, J. M., Cohen, N. L., Pillsbury, H. C., Ramsden, R. T., & Welling, D. B. (2007). Cochlear implantation in the neurofibromatosis type 2 patient: Long-term follow-up. *Laryngoscope*, *117*, 1069–1072.

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America*, *95*(2), 1085–1099.

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N. Y., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *Journal of the American Medical Association*, *303*(15), 1498–1506.

Nolle, C., Todt, I., Basta, D., Unterberg, A., Mautner, V. F., & Ernst, A. (2003). Cochlear implantation after

STUDENTS-HUB.com Uploaded By: tuka abuzneid

acoustic tumour resection in neurofibromatosis type 2: Impact of intra and postoperative neural response telemetry monitoring. *ORL Journal for Otorhinolaryngology and Its Related Specialties*, *65*, 230–234.

Park, L. R., Teagle, H. F. B., Gagnon, E., Woodard, J., & Brown, K. D. (2019). Electric-Acoustic stimulation outcomes in children. *Ear and Hearing*, 40, 849–857.

Peng, K. A., Lorenz, M. B., Otto, S. R., Brackmann, D. E., & Wilkinson, E. P. (2018). Cochlear implantation and auditory brainstem implantation in neurofibromatosis type 2. *Laryngoscope*, *128*(9), 2163–2169.

Polonenko, M. J., Papsin, B. C., & Gordon, K. A. (2015). The effects of asymmetric hearing on bilateral brainstem function: Findings in children with bimodal (electric and acoustic) hearing. *Audiology & Neuro-Otology*, *20*(Suppl. 1), 13–20.

Polonenko, M. J., Papsin, B. C., & Gordon, K. A. (2017). Delayed access to bilateral input alters cortical organization in children with asymmetric hearing. *NeuroImage Clinical*, *17*, 415–425.

Prejban, D. A., Hamzavi, J. S., Arnolder, C., Liepins, R., Honeder, C., Kaider, A., . . . Riss, D. (2018). Single sided deaf cochlear implant users in the difficult listening situation: Speech perception and subjective benefit. *Otology & Neurotology*, *39*(9), e803–e809.

Punte, A. K., Vermeire, K., Hofkens, A., De Bodt, M., De Ridder, D., & van de Heyning, P. (2011). Cochlear implantation as a durable tinnitus treatment in single-sided deafness. *Cochlear Implants International*, *12*(Suppl. 1), S26–S29.

Pyman, B., Blamey, P., Lacy, P., Clark, G., & Dowell, R. (2000). The development of speech perception in children using cochlear implants: Effects of etiologic factors and delayed milestones. *American Journal of Otology*, *21*, 57–61.

Rahne, T., & Plontke, S. K. (2016). Functional result after cochlear implantation in children and adults with single-sided deafness. *Otology & Neurotology*, *37*(9), e332–e340.

Rajan, G., Tavora-Vieira, D., Baumgartner, W. D., Godey, B., Müller, J., O'Driscoll, M., . . . van de Heyning, P. (2018). Hearing preservation cochlear implantation in children: The HEARRING Group consensus and practice guide. *Cochlear Implants International*, *19*(1), 1–13.

Ramos, Á., Polo, R., Masgoret, E., Artiles, O., Lisner, I., Zaballos, M. L., & Osorio, Á. (2012). Cochlear implant in patients with sudden unilateral sensorineural hearing loss and associated tinnitus. *Acta Otorrinolaringologica*, *63*(1), 15–20.

Roberts, C., & Hindley, P. (1999). Practitioner review: the assessment and treatment of deaf children with psychiatric disorders. *Journal of Child Psychology and Psychiatry*, *40*(2), 151–167.

Roehm, P. C., Mallen-St. Clair, J., Jethanamest, D., Golfinos, J. G., Shapiro, W., Waltzman, S., & Roland, R. T. (2011). Auditory rehabilitation of patients with neurofibromatosis type 2 by using cochlear implants. *Journal of Neurosurgery*, *115*, 827–834.

Rohlfs, A. K., Friedhoff, J., Bohnert, A., Breitfuss, A., Hess, M., Müller, F., . . . Wiesner, T. (2017). Unilateral hearing loss in children: A retrospective study and a review of the current literature. *European Journal of Pediatrics*, *176*(4), 475–486.

Sanhueza, I., Manrique, R., Huarte, A., de Erenchun, I. R., & Manrique, M. (2016). Bimodal stimulation with cochlear implant and hearing aid in cases of highly asymmetrical hearing loss. *The Journal of International Advanced Otology*, *12*(1), 16–22.

Siegbahn, M., Lundin, K., Olsson, G. B., Stillesjo, F., Kinnefors, A., Rask-Andersen, H., & Nyberg, G. (2014). Auditory brainstem implants (ABIs)—20 years of clinical experience in Uppsala, Sweden. *Acta Oto-Laryngologica*, *134*(10), 1052–1061.

Skarzynski, H., Lorens, A., Dziendziel, B., & Skarzynski, P. H. (2019). Electro-natural stimulation (ENS) in partial deafness treatment: Pediatric case series. *Otology & Neurotology*, *40*, 171–176.

Skarzynski, H., Lorens, A., Piotrowska, A., & Anderson, I. (2007). Partial deafness cochlear implantation in children. *International Joural of Pediatriac Otorhinolaryngology*, *71*(9), 1407–1413.

Skarzynski, H., Matusiak, M., Lorens, A., Furmanek, M., Pilka, A., & Skarzynski, P. H. (2016). Preservation of cochlear structures and hearing when using the Nucleus Slim Straight (CI422) electrode in children. *Journal of Laryngology and Otology*, *130*(4), 332–339.

Skinner, M. W., Binzer, S. M., Fears, B. T., Holden, T. A., Jenison, V. W., & Nettles, E. J. (1992). Study of the performance of four prelinguistically or perilinguistically deaf patients with a multi-electrode, intracochlear implant. *Laryngoscope*, *102*, 797–806.

Sladen, D. P., Gifford, R. H., Haynes, D. S., Kelsall, D., Benson, A., Lewis, K., . . . Driscoll, C. L. (2017). Evaluation of a revised indication for determining adult cochlear implant candidacy. *Laryngoscope*, *127*(10), 2368–2374.

Snik, A. F., Makhdoum, M. J., Vermeulen, A. M., Brokx, J. P., & van den Broek, P. (1997). The relation between age at the time of cochlear implantation and long-term speech perception abilities in congenitally deaf subjects. *International Journal of Pediatric Otorhinolaryngology*, *20*(4), 121–131.

Snik, A. F., Vermeulen, A. M., Geelen, C. P., Brokx, J. P., & van der Broek, P. (1997). Speech perception performance of congenitally deaf patients with a cochlear

STUDENTS-HUB.com Uploaded By: tuka abuzneid

implant: The effect of age at implantation. *American Journal of Otology*, *18*(6 Suppl.), S138–S139.

Sorkin, D. L. (2013). Cochlear implantation in the world's largest medical device market: utilization and awareness of cochlear implants in the United States. *Cochlear Implants International*, *14*(1), 4–12. https://doi.org/10.1179/1467010013Z.000000000102

Sorkin, D. L. (2019). Impact of Medicaid on cochlear implant access. *Otology & Neurotology*, *40*, e336–e341.

Sorkin, D. L., & Buchman, C. A. (2016). Cochlear implant access in six developed countries. *Otology & Neurotology*, *37*(2), e161–164.

Spahr, A. J., Dorman, M. F., Litvak, L. M., Wie, S. Van, Gifford, R. H., Loizou, P. C., . . . Cook, S. (2012). Development and validation of the AzBio sentence lists. *Ear and Hearing*, *33*(1), 2–7.

Stern, R. E., Yeuh, B., Lewis, C., Norton, S., & Sie, K. C. Y. (2005). Recent epidemiology of pediatric cochlear implantation in the United States: Disparity among children of different ethnicity and socioeconomic status. *The Laryngoscope*, *115*, 125–131.

Steven, R. A., Green, K. M., Broomfield, S. J., Henderson, L. A., Ramsden, R. T., & Bruce, I. A. (2011). Cochlear implantation in children with cerebral palsy. *International Joural of Pediatriac Otorhinolaryngology*, *75*(11), 1427–1430.

Straatman, L. V., Rietveld, A. C., Beijen, J., Mylanus, E. A., & Mens, L. H. (2010). Advantage of bimodal fitting in prosody perception for children using a cochlear implant and a hearing aid. *Journal of the Acoustical Society of America*, *128*(4), 1884–1895.

Tajudeen, B. A., Waltzman, S. B., Jethanamest, D., & Svirsky, M. A. (2010). Speech perception in congenitally deaf children receiving cochlear implants in the first year of life. *Otology & Neurotology*, *31*, 1254–1260.

Temple, R. H., Axon, P. R., Ramsden, R. T., Keles, N., Deger, K., & Yucel, E. (1999). Auditory rehabilitation in neurofibromatosis type 2: A case for cochlear implantation. *Journal of Laryngology & Otology*, *113*, 161–163.

Teoh, S. W., Pisoni, D. B., & Miyamoto, R. T. (2004). Cochlear implantation in adults with prelingual deafness. Part I. Clinical results. *Laryngoscope*, *114*, 1536–1540.

Tharpe, A. M. (2008). Unilateral and mild bilateral hearing loss in children: Past and current perspectives. *Trends in Amplification*, *12*(1), 7–15.

Tobey, E. A., Thal, D., Niparko, J. K., Eisenberg, L. S., Quittner, A. L., & Wang, N. Y. (2013). Influence of implantation age on school-age language performance in pediatric cochlear implant users. *International Journal of Audiology*, *52*(4), 219–229.

Tomblin, J. B., Barker, B. A., Spencer, L. J., Zhang, X., & Gantz, B. J. (2005). The effect of age at cochlear implant initial stimulation on expressive language growth in infants and toddlers. *Journal of Speech Language and Hearing Research*, *48*, 853–867.

Tomblin, J. B., Spencer, L., Flock, S., Tyler, R., & Gantz, B. (1999). A comparison of language achievement in children with cochlear implants and children using hearing aids. *Journal of Speech and Language*, *42*, 497–509.

Tong, Y. C., Busby, P. A., & Clark, G. M. (1988). Perceptual studies on cochlear implant patients with early onset of profound hearing impairment prior to normal development of auditory, speech, and language skills. *Journal of the Acoustical Society of America*, *84*(3), 951–962.

Tono, T., Ushisako, Y., & Morimitsu, T. (1996). Cochlear implantation in an intralabyrinthine acoustic neuroma patient after resection of an intracanalicular tumour. *Journal of Laryngology and Otology*, *110*, 570–573.

Tran Ba Huy, P., Kania, R., Frachet, B., Poncet, C., & Legac, M. S. (2009). Auditory rehabilitation with cochlear implantation in patients with neurofibromatosis type 2. *Acta Otolaryngologica*, *129*, 971–975.

Tremblay, G., Bergeron, F., & Ferron, P. (2008). Over-the-fence cochlear implantation: Is it worthwhile? *Journal of Otolaryngology-Head and Neck Surgery*, *37*(3), 440–445.

Trotter, M. I., & Briggs, R. J. (2010). Cochlear implantation in neurofibromatosis type 2 after radiation therapy. *Otology & Neurotology*, *31*, 216–219.

Uhler, K., Warner-Czyz, A., Gifford, R., & Group, P. W. (2017). Pediatric Minimum Speech Test Battery. *Journal of the American Academy of Audiology*, *28*(3), 232–247.

Valencia, D. M., Rimell, F. L., Friedman, B. J., Oblander, M. R., & Helmbrecht, J. (2008). Cochlear implantation in infants less than 12 months of age. *International Journal of Pediatric Otorhinolaryngology*, *72*, 767–773.

van de Heyning, P., Távora-Vieira, D., Mertens, G., Van Rompaey, V., Rajan, G. P., Müller, J., . . . Zernotti, M. E. (2016). Towards a unified testing framework for single-sided deafness studies: A consensus paper. *Audiology and Neuro-Otology*, *21*(6), 391–398.

van de Heyning, P., Vermeire, K., Diebl, M., Nopp, P., Anderson, I., & De Ridder, D. (2008). Incapacitating unilateral tinnitus in single-sided deafness treated by cochlear implantation. *Annals of Otology, Rhinology and Laryngology*, *117*(9), 645–652.

van Dijkhuizen, J. N., Beers, M., Boermans, P.-P. B. M., Briaire, J. J., Frijns, J. H. M., Dijkhuizen, J. N. Van, . . . Frijns, J. H. M. (2011). Speech intelligibility as a predictor of cochlear implant outcome in prelingually deafened adults. *Ear and Hearing*, *32*(4), 445–458. https://doi.org/10.1097/AUD.0b013e31820510b7

STUDENTS-HUB.com Uploaded By: tuka abuzneid

van Loon, M. C., Smits, C., Smith, C. F., Hensen, E. F., & Merkus, P. (2017). Cochlear implantation in adults with asymmetric hearing loss: Benefits of bimodal stimulation. *Otology & Neurotology*, *38*(6), e100–e106.

Van Naarden, K., Decoufle, P., & Caldwell, K. (1999). Prevalence and characteristics of children with serious hearing impairment in metropolitan Atlanta. *Pediatrics*, *103*, 570–575.

van Zon, A., Peters, J. P., Stegeman, I., Smit, A. L., & Grolman, W. (2015). Cochlear implantation for patients with single-sided deafness or asymmetrical hearing loss: A systematic review of the evidence. *Otology & Neurotology*, *36*, 209–219.

Vermeire, K., & van de Heyning, P. (2009). Binaural hearing after cochlear implantation in subjects with unilateral sensorineural deafness and tinnitus. *Audiology and Neurotology*, *14*(3), 163–171.

Vincenti, V., Pasanisi, E., Guida, M., Di Trapani, G., & Sanna, M. (2008). Hearing rehabilitation in neurofibromatosis type 2 patients: Cochlear versus auditory brainstem implantation. *Audiology and Neurotology*, *13*, 273–280.

Waltzman, S. B., & Cohen, N. L. (1999). Implantation of patients with prelingual long-term deafness. *Annals of Otology, Rhinology and Laryngology*, *108*, 84–87.

Waltzman, S. B., & Roland, J. T. (2005). Cochlear implantation in children younger than 12 months. *Pediatrics*, *116*, 487–493.

Waltzman, S. B., Scalchunes, V., & Cohen, N. L. (2000). Performance of multiply handicapped children using cochlear implants. *American Journal of Otology*, *21*, 329–335.

Wilson, B. S., & Dorman, M. M. F. (2008). Cochlear implants: Current designs and future possibilities. *The Journal of Rehabilitation Research and Development*, *45*(5), 695–730. https://doi.org/10.1682/JRRD.2007.10.0173

Winton, L., Hollow, R., & Dettman, S. J. (2002). Cochlear implant speech perception selection criteria: Who is a candidate now? *In Proceedings of the XXVI International Congress of Audiology, March 17–21*. Melbourne, Australia.

Wong, K., Kozin, E. D., Kanumuri, V. V., Vachicouras, N., Miller, J., Lacour, S., . . . Lee, D. J. (2019). Auditory brainstem implants: Recent progress and future perspectives. *Frontiers in Neuroscience*, *13*, 10. https://doi.org/10.3389/fnins.2019.00010

Wu, E., Zardouz, S., Rothholtz, V., German, M., & Djalilian, H. (2010). Primary care physicians' knowledge of cochlear implantation. *Otolaryngology-Head and Neck Surgery*, *143*, P244.

Zeitler, D. M., Dorman, M. F., Natale, S. J., Loiselle, L., Yost, W. A., & Gifford, R. H. (2015). Sound source localization and speech understanding in complex listening environments by single-sided deaf listeners after cochlear implantation. *Otology and Neurotology*, *36*(9).

Zeitler, D. M., Sladen, D. P., DeJong, M. D., Torres, J. H., Dorman, M. F., & Carlson, M. L. (2019). Cochlear implantation for single-sided deafness in children and adolescents. *International Journal of Pediatric Otorhinolaryngology*, *118*, 128–133.

Zwolan, T. A., Kileny, P. R., & Telian, S. A. (1996). Self-report of cochlear implant use and satisfaction by prelingually deafened adults. *Ear and Hearing*, *17*(3), 198–210.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

7

Elements of Postoperative Assessment in Adult Implant Recipients

René H. Gifford

INTRODUCTION

Determining a reliable and efficacious assessment protocol for the evaluation of speech perception has been, and will continue to be, an evolutionary process. Mackersie (2002) describes the ideal speech perception test as being reliable, highly sensitive to differences between testing conditions, and having a high degree of correlation with real-world speech understanding. Across-test correlation or agreement is also an important consideration in the choice of metrics. As discussed in Chapter 2, the Minimum Speech Test Battery (MSTB) represents current best practices for pre- and postimplant assessment of speech recognition for adult implant candidates and recipients. There are, however, many factors to be considered in the postoperative assessment of adult implant recipients other than the *exact measures* to be used.

This chapter discusses the process of postoperative assessment of performance for adult cochlear implant recipients including aspects to be considered from the perspective of all members of the implant team.

POSTIMPLANT AUDIOLOGIC EVALUATION

Assessment of Acoustic Hearing Status

Implanted Ear

STUDENTS-HUB.com Uploaded By: tuka abuzneid

As mentioned in Chapter 2, preoperative assessments include obtaining audiometric thresholds for octave frequencies 125 to 8000 Hz. Thresholds at 125 Hz are particularly important given that otologists, audiologists, and even patients are increasingly aware of the possibilities of hearing preservation with cochlear implantation (Carlson et al., 2011; Roland, Gantz, Waltzman, & Parkinson, 2016; Skarzynski et al., 2018; Suhling et al., 2016; Wanna et al., 2018; Woodson, Reiss, Turner,

Gfeller, & Gantz, 2009). It is recommended that postoperative audiometric testing be completed first at the initial activation appointment. This test point provides us with the clearest picture of the impact that the surgical placement of the device has had on residual cochlear function. It also provides a baseline against which future measurements of residual acoustic hearing can be compared.

At this initial activation appointment, obtaining both air-conduction and bone-conduction thresholds is critical. The reason is that residual blood and/or fluid may still be present in the middle ear space. For that reason, a conductive component is likely present at initial activation and without bone conduction audiometry, we would not have this information. Tympanograms can also be completed and can verify the presence of fluid, though it is recommended that the audiology team first discuss this protocol with the surgical team to gain medical clearance, particularly for initial activations occurring sooner than 2 weeks after surgery.

In cases of hearing preservation, it is our role as clinicians to monitor this hearing over time. Over the first year of implant use, obtaining pure-tone thresholds in the implanted ear *at least one additional time* beyond the initial activation appointment is recommended. This is particularly true in cases for which a conductive overlay was initially present. Multiple studies have documented a persistent air-bone gap for hearing preservation cases (Chole, Hullar, & Potts, 2014; Mattingly, Uhler, & Cass, 2016; Raveh, Attias, Nageris, Kornreich, & Ulanovski, 2014). This persistent conductive component is not completely understood, but is thought to reflect alterations in cochlear mechanics due to presence of the implanted array and scar tissue impacting basilar membrane velocity (Banakis et al., 2016; Choi & Oghalai, 2005; Raveh et al., 2014). Previous studies have hypothesized that this conductive component may be due to a third window effect resulting from the presence of an electrode array in the round window, or more commonly, a cochleostomy or extended round window approach (Dedhia, Worman, Meredith, & Rubinsteini, 2016; Raveh et al., 2014); however, Banakis, Hartl, and colleagues demonstrated that altered cochlear mechanics due to the implanted electrode array affect air conduction, but not bone conduction mechanisms (Banakis et al., 2016).

It is the responsibility of each program to develop its own protocols regarding postoperative hearing assessment in the implanted ear. It makes practical sense to assess hearing in the implanted ear at intervals that also include sound booth testing, such as the 6- and/or 12-month appointments. The assessment of residual hearing in the implanted ear will be an issue of further audiologic management as we investigate the possibility of providing acoustic amplification in that ear.

In addition to the assessment of residual acoustic hearing in the implanted ear(s), we must also consider whether the integrated hearing aid—acoustic component or acoustic earhook—is providing target audibility. According to the American Academy of Audiology's Guidelines for the Audiologic Management of Adult Hearing Impairment (Valente et al., 2006), electroacoustic verification of hearing aid settings should be completed, at a minimum, on an annual basis. At Vanderbilt, our clinical cochlear implant protocol involves assessing acoustic hearing preservation in the implanted ear at each programming appointment in the first year following surgery (activation, 1 month, 3 month, 6 month, and 12 month) and annually thereafter. Additionally, for each appointment that cochlear implant programming is completed, we will also verify that the integrated hearing aid component is providing target audibility and can reference against the unaided audiometric thresholds obtained on that same date. We will often obtain a real-ear-to-coupler-difference (RECD) for our patients at the preoperative or activation appointment and then complete subsequent verifications in the coupler.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Nonimplanted Ear (Bimodal Listeners)

In addition to assessing residual hearing in the implanted ear, we must also continue to manage the hearing and associated effectiveness and appropriateness of amplification in the nonimplanted ear for our bimodal patients. All too often cochlear implant audiologists focus so much on the implanted ear that the non-implanted ear

goes unnoticed. We must not forget that in order to assess postoperative speech recognition in the best-aided condition, we should complete regular pure tone audiometric testing *and* probe-microphone measurements of the hearing aid to verify settings. As described above, the American Academy of Audiology's best practices guidelines (Valente et al., 2006) dictate that electroacoustic verification should be completed, at a minimum, on an annual basis. Hearing aid verification, however, is only as good as the accuracy of one's audiometric thresholds; thus, we should assess hearing in the non-implanted ear on an annual basis or more frequently should our patient report perceptual changes. Another consideration here is that annual unaided audiometry and accompanying hearing aid verification must be completed if we are to assess speech recognition in a verified bimodal listening condition. That is, we cannot accurately present outcomes for the bimodal hearing condition if we have not verified that the patient is fitted appropriately from a bimodal perspective.

Cochlear Implant "Aided" Audiometric Thresholds

Hearing aid audibility can be measured via SPL in the ear canal at various input signal levels. Cochlear implants, however, transmit the signal across the skin via radio-frequency transmission; thus, a physical output level cannot be *directly* measured. This does not mean that we cannot attempt to estimate minimum audibility for a recipient's program. Skinner and colleagues discussed the function of sound field audiometric thresholds for determining the minimum audibility available for implant recipients (Skinner, Holden, Holden, & Demorest, 1999; Skinner, Holden, Holden, Demorest, & Fourakis, 1997). On the basis of their work, it has become standard practice to optimize cochlear implant mapping to achieve aided sound field thresholds in the range of 20 to 30 dB HL (for 250 to 6000 Hz) for adult recipients. Documenting sound field thresholds in the range of 20 to 30 dB HL provides us with an assurance of audibility for low-level stimuli, such as soft speech (Skinner et al., 1997).

Given that we will already be in the sound booth obtaining aided sound field thresholds for the implanted ear, clinicians might be tempted to substitute functional gain measures for probe-microphone measurements in the non-implanted ear (bimodal) and/or in the implanted ear(s). This should be avoided, because functional gain measures do not verify hearing aid settings, do not provide information regarding the input/output characteristics of hearing aids and thus cannot verify ear canal audibility for multiple input levels in the range of low-, high-, and conversational-level speech. In 2006, the American Academy of Audiology published the *Guidelines for the Audiologic Management of Adult Hearing Impairment* (Valente et al., 2006), which states "prescribed gain from a validated prescriptive method should be verified using a probe microphone approach that is referenced to ear canal SPL." Thus, functional gain measures are not appropriate for verification of hearing aid settings as part of the postoperative assessment. The only reason we use an analog of "functional gain" for cochlear implant audibility is that we do not currently have an alternative.

Microphone Check

Another important note is that although aided sound field thresholds provide verification of implant mapping for low-level inputs, there is no substitution for an old-fashioned mic check. Pediatric audiologists routinely listen to implant processor microphones to check for low-level humming, static, or any variation of compromised sound quality. One might argue that mic checks are even more important for adult implant recipients because pediatric recipients have parents, educators, and clinicians who routinely check for microphone issues, whereas adult recipients may not have a partner who checks equipment. Microphone checks are just another valuable tool for postoperative assessment of patient performance.

Calibration and Test Conditions

Sound field calibration is completely dependent on the test conditions for the patients in the test booth. For adult sound field audiometry, the loudspeaker is typically placed directly in front of the

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 7–1. Frequency-Specific Correction Factors for Sound-Field Threshold Estimation Referencing Calibration at 0º Azimuth

Frequency (Hz)	45º (dB)	90º (dB)
125	0.5	1.0
250	1.0	2.0
500	3.0	4.5
750	3.5	3.0
1000	4.0	5.5
1500	1.5	0.0
2000	3.0	2.0
3000	5.0	2.5
4000	4.0	-0.5
6000	7.5	9.5
8000	5.5	8.5

listener (0º azimuth) at a distance of approximately 1 to 1.5 m (approximately 3.3 to 4.9 feet); thus, if a sound booth is being used exclusively for adult hearing assessment, the sound field will most likely be calibrated for loudspeaker placement at 0º azimuth. In many audiology clinics, however, sound booths are set up such that both adults and children can be tested, that is, there are loudspeakers placed at ±45 to 90º allowing for visual reinforcement audiometry. If this is the case, the sound field will most likely be calibrated assuming loudspeaker placement to the side of the listener (at either ±45 to 90º); thus, it is critical that the appropriate correction factors be used when placing an adult listener in the booth facing the loudspeaker. Table 7–1 displays the frequency specific correction factors to be used when characterizing sound field audiometric thresholds in a room that was calibrated for 0º azimuth (ANSI, 2004; ISO 8253-2, 1998). If you are unsure whether your audiometer sound field has been calibrated for 0º, 45º, or 90º azimuth, consult your audiometer calibration certificate or acoustical engineer responsible for calibration.

Stimulus for Testing: Frequency-Modulated Tones and Narrow-Band Noise

There are just two types of audiometer-derived stimuli appropriate for obtaining sound field thresholds: frequency-modulated (FM) or warbled tones and narrowband noise. Audiologists are aware of the need for FM or warbled tones in the sound field to avoid problems associated with standing waves; however, many clinicians may not be aware of issues surrounding the use of narrow-band noise for sound field threshold estimation. All audiometers are calibrated for narrow-band noise presentation via headphones or insert earphones, for *effective masking levels*. Not all audiometers, however, are calibrated for narrow-band noise presentation via loudspeaker. Newer computer-based audiometers come equipped with a narrower band noise stimulus that is calibrated for sound field audiometry and has steeper filter slopes. The steeper filter slopes allow for more accurate, frequency specific threshold estimation than using narrowband noise, which was constructed and intended for masking purposes. Thus it is recommended that aided sound-field thresholds be obtained using warbled tones if at all possible and to document if and when narrow-band noise was used as the latter stimulus is much less frequency selective often resulting in lower (i.e., better) aided thresholds.

SPEECH-RECOGNITION TESTING

Speech-Perception Metrics

STUDENT3-HUB.com Uploaded By: tuka abuzneid

As discussed in Chapter 2, much of the preoperative assessment in this section can also be found in the 2011 MSTB manual which can be downloaded for free at http://www.auditorypotential.com/MSTB_Nav.html

The most important aspect surrounding the administration of speech recognition measures as recommended by the MSTB involves the use of recorded speech materials. As shown in Chapter 2, Figures 2–1A and 2–1B, word-recognition

scores obtained via monitored live voice (MLV) and with recorded stimuli can vary by as much as 80-percentage points for a single listener; thus, use of MLV for the assessment of speech recognition for adult implant recipients is not only not recommended, but is not considered best practices. Some clinicians argue that poorer performing recipients, such as prelingually deafened adults, require the use of MLV for assessing speech recognition; however, as discussed in Chapter 6, we may want to consider the development of a supplemental or substitution test battery when assessing pre- and post-implant performance for adults with pre- and perilingual onset of deafness. As we have been cognizant of ceiling effects with previously used metrics of speech recognition for implant recipients, such as the Central Institute for the Deaf (CID; Silverman & Hirsch, 1955) sentences, City University of New York (CUNY) sentences, and Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994) sentences, we must also be wary of floor effects. Figure 6–3 as displayed in Chapter 6 provides an example of a hypothetical battery of tests for use with prelingually deafened adults who have limited auditory skills. As discussed in Chapters 2 and 6, more than the protocol itself, what is essential is that all clinicians in a center follow the same protocol *using recorded stimuli*. Protocol adherence allows each implant program to generate its own normative data for patient outcomes, which significantly aids patient counseling. This also provides clinics with the data needed to compare outcomes with those of average patient performance as reported in the literature. Furthermore, because most implant programs have multiple clinicians, adherence to protocol along with the use of recorded stimuli allows for clinician substitution without sacrificing assessment accuracy. Although we may use a specialized battery of tests for poorer performing patients, it is important to recognize that over time, a patient may demonstrate sufficient progress to a level at which the regular adult MSTB may be used.

Table 7–2 displays the audiometric and speech recognition protocol as outlined in the MSTB for adult implant recipients. The recommended test battery has been estimated at approximately 30 to 45 min per listening condition including all measures displayed in Table 7–2. The recommended battery includes postoperative assessment of (1) unaided audiometric thresholds in the implanted ear(s); (2) aided sound field thresholds for the implanted ear(s); (3) speech recognition performance using CNC words (Peterson & Lehiste, 1962), AzBio sentences (Spahr et al., 2012), and AzBio sentences presented in multi-talker babble using a +5 dB signal-to-noise ratio or one list pair of the Bamford-Kowal-Bench-Sentence-in-noise (BKB-SIN) test (Etymotic, 2005; Killion, Niquette, Revit, & Skinner, 2001); and (4) administration of questionnaires assessing perceived benefit and/or quality of life.

Testing Conditions

The testing conditions for assessing postoperative performance are not widely agreed upon among clinicians. The MSTB manual does not provide a recommendation regarding the listening conditions or the frequency of testing for implant recipients. In 2009, a working group of clinicians, scientists, and manufacturer representatives published a recommended postoperative testing schedule (Fabry, Firszt, Gifford, Holden, & Koch, 2009). The resultant recommendations included postoperative assessment of the MSTB—though not yet part of the MSTB at the time of publication—at 1, 3, 6, and 12 months, and annually thereafter. According to the recommendations, the implanted ear should be tested at each of these intervals; thus, for bilaterally implanted individuals who are implanted in the same surgical procedure, this would require testing the right, left, and bilateral conditions four times during the first year, which equals over 60 min of testing at each appointment. However, most adult bilateral recipients are implanted in sequential surgeries, in which case only the most recently implanted ear would have to be assessed at each visit during the first year.

Table 7–3 displays a modified testing schedule based on the Fabry et al. (2009) and MSTB recommendations (MSTB, 2011). Although some clinicians may be intimidated by the testing schedule, this does not represent a professional guideline or best-practices recommendation; it is simply an example of a testing schedule derived

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 7–2. Test Battery for Postoperative Assessment of Outcomes in Adults

Audiometry and tympanometry		***Maximum time (min)***
Audiometric thresholds, 125 to 8000 Hz AC, 250 to 4000 Hz BC unaided implanted ear (AC & BC) unaided non-implanted ear, at least annually (AC & BC)	Pure tones	9.4 unilateral 18.8 bilateral
Tympanometry (for cases of conductive overlay)	226-Hz probe	3.4 unilateral 6.8 bilateral
Aided sound-field thresholds 250 to 6000 Hz (each implanted ear individually)	FM or warbled tones	4.0 unilateral 8.0 bilateral
Hearing aid verification for acoustic hearing ears using amplification		***Maximum time (min)***
Electroacoustic verification and real-ear measures	Speech or speech-like stimulus, 60 dB SPL	11.0 for unilateral 22.0 for bilateral
Aided speech-recognition testing ***Recorded stimuli, 60 dB SPL, implant alone & best-aided condition[a]***		***Maximum time (min)***
CNC	One 50-item list	3 to 5 min (9 to 15 minutes if administered in 3 conditions, e.g., CI alone, HA alone, bimodal)
AzBio sentences	One 20-sentence list	3 to 5 min (9 to 15 minutes if administered in each condition)
If AzBio sentence recognition in quiet exceeds 60%, test at +5 dB SNR		
AzBio sentences at +5 dB SNR	One 20-sentence list	3 to 5 min (9 to 15 minutes if administered in each condition)
BKB-SIN	One paired list	3 to 5 min (9 to 15 minutes if administered in each condition)
Administration of questionnaires (in waiting room prior to visit)	Questionnaires per clinical protocol	No additional appointment time

STUDENTS-HUB.com Uploaded By: tuka abuzneid

[a]Assessment of the non-implanted ear alone should be completed at least annually to track change and to determine whether the nonimplanted ear would meet cochlear implant candidacy.

Note. *AC air conduction*; *BC* bone conduction; *CNC* consonant nucleus consonant; *SNR* signal-to-noise ratio; *CI* cochlear implant; *HA* hearing aid.

Table 7–3. Modified Postoperative Testing Schedule for Aided Speech Recognition (Adult Implant Recipients)

Condition	1 month	3 months	6 months	12 months	Annually
Implanted ear(s) alone	X	X	X	X	X
Nonimplanted ear alone (unilateral recipients)				X	X
"Best aided" (e.g., bimodal or bilateral cochlear implants)	X	X	X	X	X

primarily from published recommendations (Fabry et al., 2009; MSTB, 2011). As any seasoned clinician will attest, there are patient appointments for which we may plan to complete a full postoperative assessment, but complicated equipment issues, troubleshooting, and patient counseling may preclude full assessment. Though we have protocols in place to provide us with a framework by which we practice, the best clinicians know when to deviate from the protocol and/or testing schedule in order to better serve the needs of the patient. Most important here is that the order of assessment at each test point is followed so that at a minimum, we would collect data for the same measure at each time point for which time allowed for assessment. For example, always starting with CNC word recognition in the implanted ear(s) alone condition would ensure that this measure (and listening condition) is represented longitudinally even if time did not allow for additional testing beyond CNC word recognition at subsequent time points.

Postoperative assessment is critical. Without it, we have no outcome measures on which to base the effectiveness of the intervention. For patients who have undergone an irreversible surgical procedure, it is even more critical to track postoperative performance longitudinally in order to assess the effectiveness of not just the surgery, but also our programming, the equipment, and the recommended rehabilitation strategy (e.g., bimodal vs. bilateral implantation). Aided audiometric thresholds provide only a first-pass verification for our patients, but not unlike functional gain measures, aided sound field thresholds provide information about tonal or noise-band detection. Detection represents low-level processing that, even when optimal, does not necessarily equate one's *perception* of complex stimuli such as speech. As mentioned throughout this book, it is important for each cochlear implant program to determine its own protocol based on the goals for both preoperative testing and postoperative assessment of speech understanding.

Another reason for completing regular postoperative testing is that these data are used in cases of device failure to confirm significant reduction in performance; thus, these data can help our patients obtain warranty replacement for internal device replacement. Though we do not like to think about device failures [and thankfully the percentage of failed devices is low, (Blanchard et al., 2015; Eskander et al., 2011; Masterson et al., 2012; Roby, Ferrello, Huang, Rimell, & Levine, 2012; Stevens et al., 2019)], failures do occur, and thus we must remain vigilant in our documentation of patient outcomes over time.

There are recent reports of adult CI patients being able to use home-based methods of speech recognition testing—via personal computer, tablet, or smartphone stimulus delivery—which may ultimately serve as substitute or supplement to clinic-based assessments (Cullington & Agyemang-Prempeh, 2017; Cullington & Aidi, 2017; Cullington et al., 2016; de Graaf et al., 2016; de Graaff, Huysmans, Merkus, Theo Goverts, & Smits, 2018). There are other reports of successful assessment of speech recognition completed remotely via clinician-led telepractice (Goehriing et al., 2012; Hughes et al., 2012). Both options are likely going to become part of our standard clinical practice and will

STUDENTS-HUB.com Uploaded By: tuka abuzneid

hopefully allow us to better track our patients' progress longitudinally.

Time Allotted for Postoperative Assessment

How much time should be allotted for postoperative assessment with adult implant recipients? This depends on the clinic protocol. Some clinics may choose to follow the full MSTB recommendations for select appointments but only include the minimum recommended testing schedule at most appointments due to time, space, and/or personnel restrictions. Other clinics may choose to incorporate the full MSTB recommendations but also obtain supplemental information, as obtained during the workup, including additional tests, questionnaires, and/or conditions. Using the MSTB's minimum recommended schedule as shown in Table 7–1, the approximate times for completion of each audiologic procedure were obtained from a time study of practice patterns for standard audiometry (Tucker, 2001) as well as for hearing aid verification (Busen & McCarthy, 2011). Time estimates for aided speech perception testing were obtained from the MSTB document itself. Table 7–2 provides time estimates for each of the procedures outlined in the MSTB. The estimates for audiometry and hearing aid verification reflect mean time estimates (in minutes) plus two standard deviations, as 95% of the expected values should fall within this range assuming a normal distribution. The time estimates for aided speech perception reflect the expected range of time (in minutes) needed for administration and scoring. Using the estimates provided in Table 7–2 and the recommended test schedule in Table 7–3, the maximum estimated time required for aided sound field threshold testing, hearing aid verification and aided speech perception testing for a bimodal patient (cochlear implant alone and the best-aided, bimodal condition) would range from 59 to 71 min. This time does not take into account reprogramming hearing aids should the patient's own hearing aid settings not be providing target audibility, nor does it include cochlear implant programming.

Though this may seem like a lot of time for testing, *most postoperative assessments will not take a full 59 to 71 minutes*; however, it is reasonable to err on the conservative side when allocating assessment time. The reason is that due to the severity of hearing loss and the highly individualized learning curve, not all patients will be able to communicate exclusively in an auditory/oral manner for the earliest postoperative periods. Thus, we may still need to provide written instructions on a large computer monitor facing the patient or have a standard set of simple written instructions for audiometry and speech perception testing that is often used at each cochlear implant evaluation.

ASSESSMENT OPTIONS FOR NON-ENGLISH SPEAKING RECIPIENTS

Up to this point, we have made assumptions about the use of speech recognition measures via recorded speech stimuli spoken in a North American English dialect. However, most cochlear implant programs will have populations of candidates and implant recipients for whom the language spoken in the home is not English. Using a non-native speech stimulus is likely neither appropriate or valid for obtaining reliable estimates of auditory only outcomes (Cutler, Garcia Lecumberri, & Cooke, 2008; Mayo, Florentine, & Buus, 1997; Nabelek & Donohue, 1984; Takata & Nabelek, 1990).

For some speech recognition measures, there are available recorded options in various languages such as the HINT (Spanish, Mandarin, Cantonese, Japanese, etc.) and AzBio (Spanish and French). However, given the diversity of languages spoken by implant candidates and recipients across the U.S. and certainly across the globe, it is not a realistic prospect to develop and validate a speech recognition measure for every potential language and dialect. For that reason, a number of non-linguistic measures of auditory function have been developed which are highly correlated with speech recognition for adult cochlear implant recipients. One task that was developed and validated for use with adult cochlear implant recipients was the Quick Spectral Modulation Detection (QSMD) task now referred to as EasyQSMD (Gifford, Hedley-Williams, & Spahr, 2014; Landsberger, Dwyer, Stupak, & Gifford, 2019). The EasyQSMD assesses spectral resolution via spectral modulation detection using a 3-interval forced

STUDENTS-HUB.com Uploaded By: tuka abuzneid

choice task with a method of constant stimuli. The electric hearing version validated for use with cochlear implant recipients uses two modulation rates (0.5 and 1.0 cyc/oct) and five modulation depths per rate (10, 11, 12, 14, and 16 dB). Each modulation rate and depth is presented 6 times for a total of 60 trials for which a final score, in percent correct, is provided for each modulation rate averaged across depths as well as a single score averaged across rate and depth. There is a significant correlation between EasyQSMD and CNC monosyllabic word recognition (Gifford et al., 2014, 2018) as well as AzBio sentences in quiet and in noise (Gifford et al., 2018) with correlation coefficients ranging from 0.5 to 0.8. The EasyQSMD takes approximately 4 to 5 minutes to administer (Landsberger et al., 2019) and can be used for individuals without concern for native language. The EasyQSMD is available for free download via: https://www.ear-lab.org/easyqsmd.html

In addition to the EasyQSMD, there are other measures of auditory function designed for use with adult cochlear implant recipients. Another measure which uses both spectral and temporal modulation of a noise band is the Spectral-temporally Modulated Ripple Test (SMRT) (Aronoff & Landsberger, 2013). The SMRT is also available for free download via: https://www.ear-lab.org/smrt.html. There are other measures that have been developed investigating both spectral ripple discrimination (Drennan, Anderson, Won, & Rubinstein, 2014), spectral-temporal modulations including the spectro-temporal modulation (STM) test (Bernstein et al., 2013) and Spectro-Temporal Ripple for Investigating Processor Effectiveness (STRIPES) (Archer-Boyd, Southwell, Deeks, Turner, & Carlyon, 2018). All of these measures have also been shown to have a significant and strong correlation with speech recognition scores.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

SUBJECTIVE EVALUATION OF POSTOPERATIVE PERFORMANCE

As mentioned in Chapter 2, measures of speech recognition performance and subjective assessments of perceived performance and/or benefit may not always be in good agreement with one another (Holder, Reynolds, Sunderhaus, & Gifford, 2018; Wackym, Runge-Samuelson, Firszt, Alkaf, & Burg, 2007; Wallhausser-Franke, Balkenhol, Hetjens, Rotter, & Servais, 2018). We have all experienced patient reports of terrible postimplant perceived benefit for patients demonstrating ceiling-level performance on measures of speech recognition. On the other hand, we have also experienced patient reports of life-altering improvements in communication only to scratch our heads at the below-average performance observed in the sound booth. A likely explanation for such discrepancies is that the laboratory-like conditions assessed in the test booth may not truly reflect real-world listening conditions; thus, it is important to utilize subjective assessment instruments that can help validate the efficacy of a particular treatment option, such as cochlear implantation. Clearly we recognize the efficacy of cochlear implantation with respect to restoration of audition—at least on a superficial, detection level—but we do not routinely assess the effect of cochlear implants on recipients' social and emotional welfare or the more global effects on quality of life. Furthermore, as noted in Chapter 2, we should be utilizing subjective assessment of communicative performance during the preimplant workup; thus, the use of subjective measures during postoperative assessment provides patient-centered information that is not necessarily gauged with standardized clinical measures of speech recognition. (See Chapter 2 for a detailed discussion of the available validated instruments.)

In addition to the validated questionnaires designed to track outcome measures and overall quality-of-life changes resulting from cochlear implantation, Chapter 2 also discusses the use of preoperative expectations questionnaires. Pre-implant expectation questionnaires allow patients to document, in writing, what they believe cochlear implants can provide for them in terms of benefit. It is not standard clinical practice to review the preoperative expectations questionnaire during postoperative assessment; however, for those patients expressing frustration regarding progress or exhibiting unrealistic expectations, review of the preoperative questionnaire serves as an excellent counseling tool, particularly for those patients expressing expectations that may differ from their own written pre-implant responses.

ROLE OF THE SOCIAL WORKER AND/OR PSYCHOLOGIST IN POSTOPERATIVE ASSESSMENT AND MANAGEMENT

As mentioned in the previous section, postoperative questionnaire data can provide useful information into the overall social and emotional well-being of our cochlear implant patients; thus, another clinical use of the postoperative questionnaire data includes identifying those individuals who may be having considerable difficulty adjusting to the cochlear implant and/or exhibiting highly unrealistic expectations despite having "passed" the preoperative candidacy workup. This information may prove useful to the cochlear implant team in order for the surgeon to make a psychological/psychiatric referral.

We often associate preoperative patients as being those most likely to suffer the psychosocial effects of hearing loss including increased incidence of depression, social anxiety, loneliness, and overall psychological distress (Abrams, Barnett, Hoth, Schultz, & Kaboli, 2006; Bosdriesz, Stam, Smits, & Kramer, 2018; Gopinath et al., 2009; Knutson, Johnson, & Murray, 2006; Nachtegaal et al., 2009). Although cochlear implantation has been shown to significantly reduce depression and other psychosocial symptoms in individuals with hearing loss (Knutson et al., 1998, 1991; Manrique-Huarte, Calavia, Huarte Irujo, Giron, & Manrique-Rodriguez, 2016; Olze et al., 2011; Poissant, Beaudoin, Huang, Brodsky, & Lee, 2008), there are still some psychological risks associated with cochlear implantation that may require postoperative referral and clinical management. Studies have shown that spouses of individuals with hearing loss exhibit elevated levels of psychological stress and anxiety (Ask, Krog, & Tambs, 2010; Brooks, Hallam, & Mellor, 2001; Hetu, Lalonde, & Getty, 1987; Hetu, Riverin, Lalande, Getty, & St-Cyr, 1988; Kelly-Campbell & Wendel, 2015; Knutson et al., 2006; Lormore & Stephens, 1994; S. Piercy & F. Piercy, 2002; Scarinci, Worrall, & Hickson, 2008); thus, it is possible that should an implant recipient not make rapid or expected progress following surgery, the level of stress within the personal relationships may also be elevated. On the other end of the spectrum, there have been reports of high-performing patients achieving increased independence and confidence, which also has the potential to affect one's personal relationships. Though these are issues clearly outside the scope of audiology, speech/language pathology, and otolaryngology, our patients often confide in us as trusted professionals, and thus these are issues about which we should be aware.

MEDICAL AND SURGICAL MANAGEMENT OF THE ADULT IMPLANT RECIPIENT

The cochlear implant surgeon, a specialist in otology or neuro-otology, plays an obviously critical role in the preoperative determination of implant candidacy. Otologists also play a critical role in the *postoperative* management of implant recipients. It is customary for surgeons to see implant patients around the time of the initial activation for postoperative check of incision, scalp flap, and reconciliation of surgically related symptoms (such as dizziness, taste disturbances, pain, etc.). This postoperative check, however, does not mark the end of the surgeon's management of the implant patient. The otologist and his or her medical team will also ensure that all cochlear implant candidates are up to date on their immunizations not only prior to cochlear implantation but also over time as the Centers for Disease Control updates the recommended booster protocol for age-specific pneumococcal vaccinations.

From an insurance-coverage perspective, Medicare requires patients to obtain a physician order for audiologic follow-up and programming. In order for the physician to be in compliance, she or he needs to maintain medical oversight of a patient's care. Notwithstanding the insurance requirement for a signed physician order for regular audiologic management, implant recipients remain under the medical care of their implanting surgeons and should thus be seen regularly for otoscopic and postauricular evaluation. Many otologists continue to see their adult implant patients on an annual or biennial basis as standard

STUDENTS-HUB.com Uploaded By: tuka abuzneid

practice. In addition to this standard practice, audiologists are undoubtedly closely acquainted with the overall otoscopic and postauricular health of implant patients and refer them for medical consultation in cases of redness, irritation, skin breakdown, electrode/device extrusion, or any other physical concern related to the implant that is outside the audiologist's scope of practice.

CONCLUSION

Postoperative assessment of outcomes is an essential component of the best-practices management for adult implant recipients. Postoperative assessment is not limited to patient-history taking regarding how well a patient thinks she or he is doing. This is standard practice for too many implant programs. Without comprehensive and frequent assessment of outcomes, including speech recognition, aided audiometric thresholds, and subjective perception of benefit and quality of life, we are not engaging in evidence-based practices. Our patients undergo an irreversible surgical procedure, and although they often sing the praises of their implants, we simply cannot provide our best programming and management without verifying our efforts. We do not need to provide our services for free because there are billable codes for postoperative assessment including CPT 92626, which can be used alone or with the 59 modifier when completing implant programming during the same appointment.

A recurrent theme of this book is that each implant program and team will develop and refine its own protocols with respect to pre- and post-implant assessment of patient performance. Though there are guidelines, such as the MSTB, each program has its own unique needs, patients, and culture. More important than the actual protocol is *adherence* to the protocol in order for the team to generate program-specific norms and for the longitudinal assessment of patient performance. Postoperative data obtained over the long term provide valuable clinical information about variability in patient performance, need for programming adjustments, equipment malfunction, address potential concerns regarding performance fluctuations, and so forth. It is expected that over time the individual metrics used in the protocol will change just as we have seen the evolution of the MSTB over the past two decades. We will be ready for these changes and will be able to document the relationship between patient performance on previous metrics with future metrics as long as we adhere to our protocols for postoperative assessment of performance.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

Abrams, T. E., Barnett, M. J., Hoth, A., Schultz, S., & Kaboli, P. J. (2006). The relationship between hearing impairment and depression in older veterans. *Journal of the American Geriatric Society, 54*(9), 1475–1477.

ANSI. (2004). *Methods for manual pure-tone threshold audiometry. American National Standards Institute, S3.21-2004*. New York, NY: Author.

Archer-Boyd, A. W., Southwell, R. V., Deeks, J. M., Turner, R. E., & Carlyon, R. P. (2018). Development and validation of a spectro-temporal processing test for cochlear-implant listeners. *Journal of the Acoustical Society of America, 144*(5), 2983.

Aronoff, J. M., & Landsberger, D. M. (2013). The development of a modified spectral ripple test. *The Journal of the Acoustical Society of America, 134*(2), EL217–222. https://doi.org/10.1121/1.4813802

Ask, H., Krog, N. H., & Tambs, K. (2010). Impact of hearing impairment on spousal mental health: The Nord-Trøndelag Health Study. *European Journal of Public Health, 20*(3), 271–275.

Banakis, R. M., Mattingly, J. K., Greene, N. T., Jenkins, H. A., Cass, S. P., & Tollin, D. J. (2016). A preliminary investigation of the air-bone gap: Changes in intracochlear sound pressure with air- and bone-conducted stimuli after cochlear implantation. *Otology & Neurotology, 37*(9), 1291–1299.

Bernstein, J. W. G., Mehraei, G., Shamma, S., Gallun, F. J., Theodoroff, S. M., & Leek, M. R. (2013). Spectro-temporal modulation sensitivity as a prediction of speech intelligibility in hearing-impaired listeners. *Journal of the American Academy of Audiology2, 24*(4), 293–306.

Blanchard, M., Thierry, B., Glynn, F., DeLamaze, A., Garabedian, E. N., & Loundon, N. (2015). Cochlear

implant failure and revision surgery in pediatric population. *Annals of Otology, Rhinology and Laryngology, 124*(3), 227–231.

Bosdriesz, J. R., Stam, M., Smits, C., & Kramer, S. E. (2018). Psychosocial health of cochlear implant users compared to that of adults with and without hearing aids: Results of a nationwide cohort study. *Clinical Otolaryngology, 43*(3), 828–834.

Brooks, D. N., Hallam, R. S., & Mellor, P. A. (2001). The effects on significant others of providing a hearing aid to the hearing-impaired partner. *British Journal of Audiology, 35*, 165–171.

Busen, J., & McCarthy, P. (2011). *Probe-microphone measurements: Commonly used or neglected?* San Diego, CA: AudiologyNOW!

Carlson, M. L., Driscoll, C. L. W., Gifford, R. H., Service, G. J., Tombers, N. M., Hughes-Borst, B. J., . . . Beatty, C. W. (2011). Implications of minimizing trauma during conventional cochlear implantation. *Otology and Neurotology, 32*(6), 962. https://doi.org/10.1097/MAO.0b013e3182204526

Choi, C. H., & Oghalai, J. S. (2005). Predicting the effect of post-implant cochlear fibrosis on residual hearing. *Hearing Research, 205*(1–2), 193–200.

Chole, R., Hullar, T., & Potts, L. (2014). Conductive component after cochlear implantation in patients with residual hearing conservation. *American Journal of Audiology, 23*(4), 359–364.

Cullington, H. E., & Agyemang-Prempeh, A. (2017). Person-centred cochlear implant care: Assessing the need for clinic intervention in adults with cochlear implants using a dual approach of an online speech recognition test and a questionnaire. *Cochlear Implants International, 18*(2), 76–88.

Cullington, H. E., & Aidi, T. (2017). Is the digit triplet test an effective and acceptable way to assess speech recognition in adults using cochlear implants in a home environment? *Cochlear Implants Internationalal, 18*(2), 97–105.

Cullington, H. E., Kitterick, P., DeBold, L., Weal, M., Clarke, N., Newberry, E., & Aubert, L. (2016). Personalised long-term follow-up of cochlear implant patients using remote care, compared with those on the standard care pathway: Study protocol for a feasibility randomised controlled trial. *BMJ Open*, *6*(5), e011342. https://doi.org/10.1136/bmjopen-2016-011342.

Cutler, A., Garcia Lecumberri, M. L., & Cooke, M. (2008). Consonant identifi cation in noise by native and non-native listeners: Effects of local context. *Journal of the Acoustical Society of America, 124*, 1264–1268.

de Graaf, F., Huysmans, E., Qazi, O. U., Vanpoucke, F. J., Merkus, P., Goverts, S. T., & Smits, C. (2016). The development of remote speech recognition tests for adult cochlear implant users: The effect of presentation mode of the noise and a reliable method to deliver sound in home environments. *Audiology and Neuro-Otology*, *21* (Suppl. 1), 48–54.

de Graaff, F., Huysmans, E., Merkus, P., Theo Goverts, S., & Smits, C. (2018). Assessment of speech recognition abilities in quiet and in noise: A comparison between self-administered home testing and testing in the clinic for adult cochlear implant users. *International Journal of Audiology, 57*(11), 872–880.

Dedhia, K., Worman, T., Meredith, M., & Rubinsteini, J. (2016). Patterns of longterm hearing loss in hearing preservation cochlear implant surgery. *Otology & Neurotology, 37*, 478–486.

Drennan, W. R., Anderson, E. S., Won, J. H., & Rubinstein, J. T. (2014). Validation of a clinical assessment of spectral-ripple resolution for cochlear implant users. *Ear and Hearing, 35*(3), e92-8. https://doi.org/10.1097/AUD.0000000000000009

Eskander, A., Gordon, K. A., Kadhim, L., Papaioannou, V., Cushing, S. L., James, A. L., . . . Papsin, B. C. (2011). Low pediatric cochlear implant failure rate: contributing factors in large-volume practice. *Archives of Otolaryngology-Head and Neck Surgery, 137*(12), 1190–1196.

Etymotic, R. (2005). BKB-SIN Test. Speech-in-Noise Test Version 1.03. Retrieved from http://www.etymotic.com

Fabry, D., Firszt, J. B., Gifford, R. H., Holden, L. K., & Koch, D. (2009). Evaluating speech perception benefit in adult cochlear implant recipients. *Audiology Today, 21*, 37–42.

Gifford, R. H., Hedley-Williams, A., & Spahr, A. J. (2014). Clinical assessment of spectral modulation detection for adult cochlear implant recipients : A non-language based measure of performance outcomes. *International Journal of Audiology, 53*(3), 159–164. https://doi.org/10.3109/14992027.2013.851800

Gifford, R. H., Noble, J. H., Camarata, S. M., Sunderhaus, L. W., Dwyer, R. T., Dawant, B. M., . . . Labadie, R. F. (2018). The relationship between spectral modulation detection and speech recognition: adult versus pediatric cochlear implant recipients. *Trends in Hearing, 22*, 1–15.

Goehriing, J. L., Hughes, M. L., Baudhuin, J. L., Valente, D. L., McCreery, R. W., Diaz, G. R., . . . Harpster, R. (2012). The effect of technology and testing environment on speech perception using telehealth with cochlear implant recipients. *Journal of Speech, Language, and Hearing Research, 55*(5), 1373–1386.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Gopinath, B., Wang, J. J., Schneider, J., Burlutsky, G., Snowdon, J., McMahon, C. M., & Mitchell, P. (2009). Depressive symptoms in older adults with hearing impairments: The Blue Mountains study. *Journal of the American Geriatrics Society, 57*(7), 1306–1308.

Hetu, R., Lalonde, M., & Getty, L. (1987). Psychosocial disadvantages associated with occupational hearing loss as experienced in the family. *Audiology, 26*, 141–152.

Hetu, R., Riverin, L., Lalande, N., Getty, L., & St-Cyr, C. (1988). Qualitative analysis of the handicap associated with occupational hearing loss. *British Journal of Audiology, 22*, 251–264.

Holder, J. T., Reynolds, S. M., Sunderhaus, L. W., & Gifford, R. H. (2018). Current profile of adults presenting for preoperative cochlear implant evaluation. *Trends in Hearing, 22*, 1–6. https://doi.org/10.1177/2331216518755288

Hughes, M. L., Goehring, J. L., Baudhuin, J. L., Dias, G. R., Sanford, T., Harpster, R., & Valente, D. L. (2012). Use of telehealth for research and clinical measures in cochlear implant recipients: A validation study. *Journal of Speech, Language and Hearing Research, 55*(4), 1112–1127.

ISO 8253-2. (1998). Acoustics—audiometric test methods, part 2: Sound field audiometry with pure tone and narrow-band test signals. *International Organization for Standardization.*

Kelly-Campbell, R. J., & Wendel, K. (2015). Measuring cognitive anxiety through the consultation process for hearing aids: Older adults and their significant others. *Journal of Communication Disorders, 56*, 29–39.

Killion, M. C., Niquette, P. A., Revit, L. J., & Skinner, M. W. (2001). Quick SIN and BKB-SIN, two new speech-in-noise tests permitting SNR-50 estimates in 1 to 2 min. *The Journal of the Acoustical Society of America, 109*(5), 2502–2502.

Knutson, J. F., Johnson, A., & Murray, K. T. (2006). Social and emotional characteristics of adults seeking a cochlear implant and their spouses. *British Journal of Health Psychology, 11*(Pt. 2), 279–292.

Knutson, J. F., Murray, K. T., Husarek, S., Westerhouse, K., Woodworth, G., Gantz, B. J., & Tyler, R. S. (1998). Psychological change over 54 months of cochlear implant use. *Ear and Hearing, 19*, 191–201.

Knutson, J. F., Schartz, H. A., Gantz, B. J., Tyler, R. S., Hinrichs, J. V., & Woodworth, G. (1991). Psychological change following 18 months of cochlear implant use. *Annals of Otology, Rhinology, and Laryngology, 110*, 877–882.

Landsberger, D. M., Dwyer, R. T., Stupak, N., & Gifford, R. H. (2019). Validating a quick spectral modulation detection task. *Ear & Hearing, 2019 April* (epub ahead of print).

Lormore, K. A., & Stephens, S. D. (1994). Use of the open-ended questionnaire with patients and their significant others. *British Journal of Audiology, 28*, 81–89.

Mackersie, C. L. (2002). Tests of speech perception abilities. *Current Opinion in Otolaryngology & Head and Neck Surgery, 10*, 392–397.

Manrique-Huarte, R., Calavia, D., Huarte Irujo, A., Giron, L., & Manrique-Rodriguez, M. (2016). Treatment for hearing loss among the elderly: Auditory outcomes and impact on quality of life. *Audiology and Neuro-Otology, 21*(Suppl. 1), 29–35.

Masterson, L., Kumar, S., Kong, J. H., Briggs, L., Donnelly, N., Axon, P. R., & Gray, R. F. (2012). Cochlear implant failures: Lessons learned from a UK centre. *Journal of Laryngology and Otology, 126*(1), 15–21.

Mattingly, J. K., Uhler, K. M., & Cass, S. P. (2016). Airbone gaps contribute to functional hearing preservation in cochlear implantation. *Otology & Neurotology, 37*(9), 1255–1262.

Mayo, L. H., Florentine, M., & Buus, S. (1997). Age of second-language acquisition and perception of speech in noise. *Journal of Speech, Language and Hearing Research, 40*, 686–693.

MSTB. (2011). Minimum speech test battery for adult cochlear implant users. Retrieved from http://auditorypotential.com/MSTBfiles/MSTBManual2011-06-20.pdf

Nabelek, A. K., & Donohue, A. M. (1984). Perception of consonants in reverberation by native and nonnative listeners. *Journal of the Acoustical Society of America, 75*, 632–634.

Nachtegaal, J., Smit, J. H., Smits, C. A. S., Bezemer, P. D., Van Beek, J. H., Festen, J. M., & Kramer, S. E. (2009). The association between hearing status and psychosocial health before the age of 70 years: Results from an Internet-based national survey on hearing. *Ear and Hearing, 30*(3), 302–312.

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America, 95*(2), 1085–1099.

Olze, H., Szczepek, A. J., Haupt, H., Förster, U., Zirke, N., Gräbel, S., & Mazurek, B. (2011). Cochlear implantation has a positive influence on quality of life, tinnitus, and psychological comorbidity. *The Laryngoscope, 121*(10), 2220–2227.

Peterson, G. E., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech and Hearing Disorders, 27*, 62–72.

STUDENTS-HUB.com Uploaded By: tuka alquzneid

Piercy, S. K., & Piercy, F. P. (2002). Couple dynamics and attributions when one partner has an acquired hearing loss: Implications for couple therapy. *Journal of Marital and Family Therapy, 28*(3), 315–326.

Poissant, S. F., Beaudoin, F., Huang, J., Brodsky, J., & Lee, D. J. (2008). Impact of cochlear implantation on speech understanding, depression, and loneliness in the elderly. *Journal of Otolaryngology-Head and Neck Surgery, 37*(4), 488–494.

Raveh, E., Attias, J., Nageris, B., Kornreich, L., & Ulanovski, D. (2014). Pattern of hearing loss following cochlear implantation. *European Archives of Oto-Rhino-Laryngology, 272*(9), 2261–2266.

Roby, B. B., Ferrello, M., Huang, T. C., Rimell, F. L., & Levine, S. C. (2012). Symptom timeline preceding cochlear implant failure: An institutional experience. *Otolaryngology-Head and Neck Surgery, 146*(5), 782–787.

Roland, J. T., Gantz, B. J., Waltzman, S. B., & Parkinson, A. J. (2016). United States multicenter clinical trial of the cochlear nucleus hybrid implant system. *Laryngoscope, 126*(1), 175–181. https://doi.org/10.1002/lary.25451

Scarinci, N., Worrall, L., & Hickson, L. (2008). The effect of hearing impairment in older people on the spouse. *International Journal of Audiology, 47*, 141–151.

Silverman, S. R., & Hirsch, I. J. (1955). Problems related to the use of speech in clinical audiometry. *Annals of Otology, Rhinology and Laryngology, 64*, 1234–1244.

Skarzynski, H., Matusiak, M., Furmanek, M., Pilka, A., Wlodarczyk, E., Oldak, M., & Skarzynski, P. H. (2018). Radiologic measurement of cochlea and hearing preservation rate using slim straight electrode (CI422) and round window approach. *Acta Otorhinolaryngologica Italica, 38*(5), 468–475.

Skinner, M. W., Holden, L. K., Holden, T. A., & Demorest, M. E. (1999). Comparison of two methods for selecting minimum stimulation levels used in programming the Nucleus 22 cochlear implant. *Journal of Speech, Language, and Hearing Research, 42*, 814–828.

Skinner, M. W., Holden, L. K., Holden, T. A., Demorest, M. E., & Fourakis, M. S. (1997). Speech recognition at simulated soft, conversational, and raised-to-loud vocal efforts by adults with cochlear implants. *Journal of the Acoustical Society of America, 101*(6), 3766–3782.

Spahr, A. J., Dorman, M. F., Litvak, L. M., Wie, S. Van, Gifford, R. H., Loizou, P. C., . . . Cook, S. (2012). Development and validation of the AzBio sentence lists. *Ear and Hearing, 33*(1), 2–7.

Stevens, S. M., Dougherty, H., Wenstrup, L., Hammer, T., Cole, T., Redmann, A., . . . Samy, R. N. (2019). Is hard failure still a common indication for revision surgery in adult cochlear implant recipients? *Otology & Neurotology, 40*(3), 321–327.

Suhling, M. C., Majdani, O., Salcher, R., Leifholz, M., Buchner, A., Lesinski-Schiedat, A., & Lenarz, T. (2016). The impact of electrode array length on hearing preservation in cochlear implantation. *Otology & Neurotology, 37*(8), 1006–1015.

Takata, Y., & Nabelek, A. K. (1990). English consonant recognition in noise and in reverberation by Japanese and American listeners. *Journal of the Acoustical Society of America, 88*, 663–666.

Tucker, M. (2001). *A time study of audiological practice patterns and the impact of reimbursement changes from third-party payers*. Theses and dissertations. Paper 1543.

Valente, M., Abrams, H., Benson, D., Chisolm, T., Citron, D., Hampton, D., & Sweetow, R. (2006). Guidelines for the audiologic management of adult hearing impairment. *Audiology Today, 18*(5), 32–36.

Wackym, P. A., Runge-Samuelson, C. L., Firszt, J. B., Alkaf, F. M., & Burg, L. S. (2007). More challenging speech perception tasks demonstrate binaural benefit in bilateral cochlear implant users. *Ear and Hearing, 28*, 80S–85S.

Wallhausser-Franke, R., Balkenhol, T., Hetjens, S., Rotter, N., & Servais, J. J. (2018). Patient benefit following bimodal CI-provision: Self-reported abilities vs. hearing status. *Frontiers in Neurology, 9*, 753. https://doi.org/10.3389/fneur.2018.00753

Wanna, G. B., O'Connell, B. P., Francis, D. O., Gifford, R. H., Hunter, J. B., Holder, J. T., . . . Haynes, D. S. (2018). Predictive factors for short- and long-term hearing preservation in cochlear implantation with conventional-length electrodes. *Laryngoscope, 128*(2), 482–489.

Woodson, E. A., Reiss, L. A. J., Turner, C. W., Gfeller, K., & Gantz, B. J. (2009). The hybrid cochlear implant: A review. *Cochlear Implants and Hearing Preservation, 67*, 125–134. https://doi.org/10.1159/000262604

STUDENTS-HUB.com Uploaded By: tuka abuzneid

8

Elements of Postoperative Assessment: Pediatric Implant Recipients

René H. Gifford

INTRODUCTION

Protocols for evaluating the postoperative performance of pediatric implant recipients are as fluid as a child's interest. This is particularly true for our youngest patients. Just as discussed in Chapter 7, the ideal speech perception test should be reliable, sensitive to differences between testing conditions, and have a high degree of correlation with real world speech understanding (Mackersie, 2002). The biggest obstacle for postoperative management of pediatric implant patients is the gathering of information from a child who is pre- or peri-verbal. Although challenging, it is not impossible and should remain a central goal of each postoperative programming visit. It is our role as clinicians to ensure that a child's amplification—whether it is with cochlear implants and/or hearing aids—is appropriate and that the amplification is maximizing each child's auditory potential. There are many factors to be considered in the postoperative assessment of pediatric cochlear implant recipients other than just the *exact measures* to be used. This chapter will discuss the process of postoperative assessment of performance for pediatric implant recipients of including aspects to be considered from the perspective of all members of the implant team.

POSTIMPLANT AUDIOLOGIC EVALUATION

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Cochlear Implant "Aided" Audiometric Thresholds

Because cochlear implants transmit the signal across the skin via radio frequency transmission, the physical *output* level cannot be *directly* measured as it the case with hearing aids. We can, however, still estimate the minimum audibility levels for a child's implant map. As discussed in Chapter 7, Skinner and colleagues discussed the

function of sound-field, audiometric thresholds for determining the minimum audibility available for implant recipients (Skinner, Holden, Holden, & Demorest, 1999; Skinner, Holden, Holden, Demorest, & Fourakis, 1997). It is considered best practices to optimize cochlear implant mapping to achieve aided sound-field thresholds in the range of 20 to 25 dB HL (for 250 through 6000 Hz) for pediatric implant recipients. For children with bilateral implants, aided sound-field thresholds should be obtained individually for each ear so as to allow for individual ear map optimization.

Note that desired sound-field thresholds for children are slightly lower (i.e., better) than our target-aided threshold range for adult implant recipients. Documenting sound-field thresholds in the range of 20 to 25 dB HL provides us with an assurance of audibility for low-level stimuli, such as soft speech (Skinner et al., 1997). The reason is that "soft" speech levels are in the range of 45 to 50 dB SPL (Pearsons, Bennett, & Fidell, 1977), which puts phonemic content of soft speech as low as 15 dB HL (Mueller & Killion, 1990). Because children are actively acquiring speech and language via the implant sound processors, it is considered more critical to achieve audibility for various levels of speech than even for adult implant recipients. As stated in the American Academy of Audiology's Pediatric Amplification Protocol (2003), "the primary goal is audibility of speech regardless of input level or vocal effort." Given this, some clinicians believe that lower aided thresholds, ≤15 dB HL, are better for pediatric outcomes. However, aided thresholds ≤15 dB HL are highly problematic as we are introducing considerable noise to the input dynamic range and increasing the likelihood of audible circuit noise. Lower is not necessarily better when it comes to optimizing audibility for our pediatric implant recipients—20 to 25 dB HL remains the goal with an occasional threshold at 15 dB HL also being acceptable. See Figure 8–1.



FIGURE 8–1. Child in sound booth completing conditioned play audiometry for aided sound-field thresholds.

Microphone Listening Check

Another important note is that although aided sound-field thresholds provide verification of implant mapping for low-level inputs, there is no substitution for a listening check of the sound processor microphone. Pediatric audiologists routinely listen to implant processor microphones to check for low-level humming, static, or any variation of compromised sound quality. Though we recommend that parents and educators routinely listen to the microphone of the sound processor(s), we should not rely solely on parental report as clinicians simply have more experience listening to microphones and are thus, more attuned to slight deviations from normal. Microphone listening checks remains a low tech, yet highly important tool for postoperative assessment of performance.

Calibration and Test Conditions

Table 7–1 in Chapter 7 displays frequency specific correction factors for sound-field threshold estimation referencing a 0° azimuth calibration. For additional detailed information regarding issues central to sound-field calibration for aided sound-field thresholds, please refer to Chapter 7, section entitled ***Calibration and Test Conditions***.

Stimulus for Testing: Frequency Modulated (FM) Tones or Narrowband Noise

There are just two types of audiometer-derived stimuli appropriate for obtaining sound-field

STUDENTS-HUB.com Uploaded By: tuka abuzneid

thresholds: frequency modulated (FM) or warbled tones and narrow band noise. All pediatric audiologists are aware of the need for FM or warbled tones in the sound field to avoid problems associated with standing waves. However, many clinicians may not be aware of issues surrounding the use of narrowband noise for sound-field threshold estimation. All audiometers will be calibrated for narrowband noise presentation via headphone or insert earphone, for the purpose of achieving *effective masking levels*. Not all audiometers, however, will be calibrated for narrowband noise presentation via loudspeaker in dB HL. Newer computer-based audiometers come equipped with a narrower band noise stimulus that are calibrated for sound-field audiometry and has steeper filter slopes, which allows for more accurate, frequency-specific threshold estimation than using narrowband noise intended for masking purposes.

Assessment of Acoustic Hearing Status

Implanted Ear

As mentioned in Chapters 2 and 7, otologists, audiologists, and even patients are increasingly aware of the possibilities of hearing preservation with cochlear implantation (Carlson et al., 2011; Roland, Gantz, Waltzman, & Parkinson, 2016; Skarzynski et al., 2018; Suhling et al., 2016; Wanna et al., 2018; Woodson, Reiss, Turner, Gfeller, & Gantz, 2009). Hearing preservation is not limited to adult implant recipients. In fact, children with residual low-frequency hearing are being implanted at increasing rates—particularly for those children with precipitously sloping hearing losses who are not making auditory progress with appropriately fitted hearing aids (Brown, Hullar, Cadieux, & Chole, 2010; Carlson et al., 2017; Dedhia, Worman, Meredith, & Rubinstein, 2016; Kuthubutheen, Hedne, Krishnaswamy, & Rajan, 2012; Park, Teagle, Gagnon, Woodard, & Brown, 2019; Rajan et al., 2018; Skarzynski & Lorens, 2010; Skarzynski et al., 2016). Pediatric implant recipients with considerable low-frequency acoustic hearing tend to be older than the typical pediatric implant recipient and thus assessment of postoperative preserved acoustic hearing is generally possible—even at the initial activation appointment.

At the initial activation appointment—or shortly thereafter—obtaining both air conduction and bone conduction thresholds will be critical to the assessment of acoustic hearing preservation. Residual blood and/or fluid may still be present in the middle ear space from the surgical procedure. Tympanograms may also be completed to verify the presence of middle ear fluid—though it is recommended that the audiology team first discuss this protocol with the surgical team to gain medical clearance (particularly for initial activations occurring sooner than 2 weeks after surgery).

In cases of acoustic hearing preservation, it is our role to monitor this hearing over time. Over the first year of implant use, obtaining pure tone audiometric thresholds in the implanted ear *at least one other time* beyond the initial activation appointment is recommended. This is particularly true in cases for which a conductive overlay was initially present. One may question the utility of assessing acoustic hearing preservation for the implanted ear, as there are no clinical guidance documents regarding the timing of fitting of an acoustic component or earhook in the implanted ear for pediatric cochlear implant recipient. Although it is likely not best fitted at activation, there is no reason that we couldn't fit the acoustic component or earhook by one month, particularly if we will want to obtain a custom earmold. Children with acoustic hearing preservation derive significant benefit from combined electric and acoustic stimulation (EAS) (Park et al., 2019; Wolfe et al., 2017); however, we have limited knowledge about this population regarding recommended fitting practices, expected benefit, and longevity of preserved acoustic hearing. We should expect a flurry of research to emerge in this space over the next decade.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Nonimplanted Ear (Bimodal Listeners)

In addition to assessing residual hearing in the implanted ear, we will also continue to manage the hearing and associated effectiveness and appropriateness of amplification in the nonimplanted ear for our patients with bimodal

hearing. Pediatric audiologists already do a great job of managing the whole child—including the hearing aid and cochlear implant. However, it remains tempting to focus almost entirely on the implanted ear such that the nonimplanted ear gets neglected. We must not forget that in order to assess the effectiveness of the hearing modality in the child's speech/language development and speech understanding, we must ensure that we are truly assessing the *best-aided* condition. Even for our youngest patients, we should be completing (1) regular pure-tone audiometry—whether it be via visual reinforcement audiometry, conditioned play audiometry, or conventional audiometry for older children—*and* (2) probe microphone measurements to verify hearing aid settings.

According to the American Academy of Audiology's Pediatric Amplification Protocol, best practices requires that hearing aids be verified using either probe microphone measurements or test box verification with patient-specific real ear to coupler difference (RECD) corrections (American Academy of Audiology, 2003). Further, given that nonlinear hearing aid circuitry is generally used to attain audibility at various input levels, a prescriptive formula such as DSL v5.0 (Cornelisse, Seewald, & Jamieson, 1995; Scollie et al., 2005; Seewald, Ross, & Spiro, 1985) should be used to verify target audibility at speech input levels corresponding to soft, average and loud, such as 50, 60 and 70 dB SPL. Note that the RECD should be measured every time the child has an earmold change and/or any time there is a change in middle ear status. For older children who are not getting earmold remakes as often as younger children and infants, RECD measures should be repeated on an annual basis to coincide with the annual hearing assessment.

Of importance is that clinicians avoid any temptations to use functional gain measures in lieu of probe microphone measurements for hearing aid verification in bimodal and/or hearing preservation patients using EAS. Such temptations may arise given that we will already be heading to the sound booth for aided implant thresholds and parents may even request hearing aid thresholds be placed on the audiogram. As mentioned in Chapter 7, this must be avoided as functional gain measures do not verify hearing aid settings nor provide information regarding the input/output characteristics of hearing aids and thus cannot verify ear-canal audibility for multiple input levels in the range of low-, high-, and conversational-level speech. If one wants to obtain functional gain measurements with the implant and hearing aid individually, as long as not considered a substitute for real ear measures, this may be completed and used for counseling purposes and to explain the differences in verification techniques across implants and hearing aids to the child's family.

ASSESSMENT OF SPEECH RECOGNITION ABILITIES

Recorded Materials

A central component of postoperative assessment for pediatric cochlear implant recipients for older children involves the behavioral assessment of aided speech recognition abilities. Many children with hearing loss may continue to rely heavily on visual cues such as lip reading and more global, nonverbal communication. Thus, in order to gain an understanding of a child's auditory-based speech recognition abilities—and more importantly, to ensure that we are maximizing auditory-oral speech understanding—speech stimuli are presented without visual cues.

A critical aspect of speech recognition testing for older children involves the use of recorded speech materials. As shown in Chapter 2, Figure 2–1, the variability associated with monitored live voice (MLV) presentation does not lend itself well to the assessment of pediatric cochlear implant outcomes. As discussed in Chapter 3, Uhler and colleagues demonstrated that there was an average 13 percentage point difference (range: 0- to 28 percentage points) between MLV and recorded stimulus presentation for a group of 29 pediatric cochlear implant recipients aged 4 to 17 years (Uhler, Biever, & Gifford, 2016). Though there are some pediatric speech metrics that are not currently available in recorded format, none of the measures that were designed for MLV presenta-

STUDENTS-HUB.com Uploaded By: tuka abuzneid

tion are indicated for use in either the determination of pediatric cochlear implant candidacy or in the postoperative assessment of outcomes as indicated in the PMSTB (Uhler, Warner-Czyz, & Gifford, 2017). As such, it is not expected that MLV is required for either pre- or postimplant assessment of pediatric implant candidates or recipients.

Despite the variability and associated problems with assessing speech recognition via MLV, depending on a child's age and/or global developmental status, MLV may still be required to elicit reliable responses. Live voice from a familiar, trusted audiologist is known to yield a simpler speech recognition task from that of a recorded speech stimulus. The recorded voice is unfamiliar and often lacks the affect that is found in the speaking style of an individual trained to work with children. It is also for this reason that overly accentuated suprasegmental features of a pediatric audiologist's spoken words, along with a slower rate of speech, may yield higher levels of speech recognition than that experienced in everyday communicative settings. Further, the test/retest reliability of speech recognition performance obtained via MLV is poorer than that for recorded stimuli (Carhart, 1946; Kruel, Bell, & Nixon, 1969) and thus it is not appropriate for longitudinal assessment of postoperative performance.

For detailed information regarding calibration of recorded stimuli for presentation in the sound field, please refer to Chapter 2, section entitled ***Testing Setup and Calibration***.

Presentation Levels

An important aspect of postoperative speech recognition testing involves the presentation levels of the recorded speech stimuli. As discussed in Chapters 2 and 3, 60 dBA represents average conversational level speech and thus it should be considered the *highest* presentation level used for assessment of postoperative outcomes. In fact, the PMSTB recommends speech recognition testing at multiple presentation levels (i.e., conversational speech in quiet [60 dBA], conversational speech in noise [65 dBA], soft speech level [50 dBA]) using a hierarchical array of speech stimuli (i.e., phonemes, words, and sentences). The addition of a lower presentation level for pediatric assessment is based on acoustic analyses of average speech levels demonstrating that, on average, casual speech levels for children and women range from 50 to 56 dBA (Table 3–1) (Olsen, 1998; Pearsons et al., 1977). In addition to average and lower level speech, we also recognize that children may not always be situated at an optimum distance from a talker, resulting in a lower ear-level SPL. Thus, PMSTB recommended assessment protocols dictate that pediatric speech recognition assessments include multiple presentation levels.

Many clinicians inquire about the HL dial setting required to achieve 50 or 60 dB SPL (A weighted)[1] in the sound booth. The answer will be completely dependent upon the material used, the source of the material, the distance between the loudspeaker and the listener, the size of the room, as well as a number of other variables. For a detailed description on the calibration of speech stimuli for presentation in the sound field to achieve set SPL levels for testing, please refer to Chapter 2, section entitled ***Testing Setup and Calibration***.

Multiple Estimates of Speech Recognition

Unlike postoperative follow-up for adult patients, pediatric cochlear implant recipients tend to be seen more frequently for routine mapping and assessment. Multiple visits provide us with frequent opportunities to not only optimize mapping but also to assess postoperative outcomes for audibility and speech recognition. Indeed the PMSTB outlines a recommended schedule for

STUDENTSHUB.com Uploaded By Rula abuzneid

[1]The use of A weighting for sound level meter measurements is recommended due to the fact that linear weighting—which is implied in an SPL reference unless otherwise specified—provides noisier recordings due to flat frequency response through the lower frequency region. In contrast, the A-weighted frequency response rolls off for lower frequencies having reached 20 dB of attenuation (relative to passband) at 100 Hz.

the frequency of assessment visits for pediatric implant recipients. For children with cochlear implants, it is recommended that children are seen every 3 months in the first year of device use and every 6 months thereafter until the child reaches school age (5 years). More frequent follow-up and assessment visits are recommended should anything change with respect to a child's auditory responsiveness, speech understanding, language development, or speech production.

Speech Perception Metrics

The PMSTB serves as our best-practices guideline for the administration and assessment of speech recognition in children with hearing loss using hearing aids and/or cochlear implants. Following cochlear implantation with maturation of a child's auditory skills and development, the chosen speech recognition measures will similarly change. It is recommended that we repeat administration of the measures used in the preoperative period so that we can demonstrate immediate growth in skills following implantation using identical measures. Age- and developmental-specific measures are discussed below.

Speech Discrimination and Recognition Test Materials: Up to 3 Years of Age

Auditory-skills development for our youngest implant recipients is typically gauged via auditory questionnaire data, parental report, and speech/language assessment. However, there are a variety of standardized measures of speech discrimination or recognition that are appropriate for the younger child. Audiologists generally begin with *closed-set tests* for which a limited set of possible choices are available and a verbal response is not required.

Visual Reinforcement Infant Speech Discrimination (VRISD)

As described in Chapter 3, VRISD is based on the principle of a conditioned head turn as used in visual reinforcement audiometry (VRA), making it ideal for use with infants between 6 and 24 months of age. Unlike conventional VRA, which requires a child to detect a sound, VRISD allows us to identify situations in which a child detects a *change in sound*. VRISD operatives via operant conditioning by reinforcing a head turn to a correct response (or a hit) using animated video or mechanical toy reinforcement. Infant speech discrimination can be assessed using several sound contrasts within a test session or across a number of test sessions. The most common speech stimuli utilized in VRISD protocols are vowel contrasts such as /a/ versus /i/ and /a/ versus /u/, which are differentiated on the basis of spectral cues. Vowel contrasts have been shown to be easier for younger infants and emerge earlier, as compared to contrasts based on voice onset time (e.g., /ta/ vs. /da/) or place of articulation (e.g., /ba/ vs. /da/) (Boothroyd, 1984; Eilers, Morse, Gavin, & Oller, 1981; Eilers, Wilson, & Moore, 1977; Uhler, Yosinaga-Itano, Gabbard, Rothpletz, & Jenkins, 2011; van Wieringer & Wouters, 1999). VRISD is typically administered until a child reaches 75% discrimination proficiency of validated and normed contrasts including /ba/ versus /da/ and /a/ versus /i/ (Uhler, Baca, Dudas, & Frederickson, 2015; Uhler et al., 2018). We do not currently have normative values for the postoperative time period for which a newly implanted child should achieve mastery for a number of phonemic contrasts. Research is ongoing in this space and we expect these data to emerge in the near future. In the interim, VRISD can still serve as a valuable tool in an audiologist's repertoire as it allows us to identify whether an infant is making gains in speech sound discrimination following implantation.

Closed Set Speech Recognition Tests

STUDENTS-HUB.com Uploaded By: tuka abuzneid

The Early Speech Perception (ESP) test includes a low verbal and standard version for word recognition (Moog & Geers, 1990). Both versions are closed-set tasks recommended for assessment of auditory skills in young children aged 2 to 5 years depending on the developmental level of the child. The low-verbal version of the ESP focuses on pattern perception of sounds and words differing by number of syllables and word stress. The ESP low-verbal version is not available in recorded format, and must thus be administered via MLV. The ESP standard version includes two subtests, including spondee

and monosyllabic word identification, respectively. Both the spondee and monosyllabic subtests requires that the child select 1 out of 12 color pictures corresponding to the spoken word. The 12 words are presented twice for a given run corresponding to a total possible of 24 correct words.

The Pediatric Speech Intelligibility (PSI; Jerger & Jerger, 1984) word and sentence tests are the most developmentally complex of the closed-set tasks included in the PMSTB. The PSI word test can be used for children as young as 3 years up to approximately 7 years of age. The PSI word task is administered by use of a carrier phrase "show me" followed by the target word. Children are instructed that they will hear a man say, "show me" and that the child should point to the picture that matches the word. Older children can simply repeat the target word. The PSI word test includes 20 words presented on 5 picture cards each containing 4 pictures.

The PSI sentence test includes two closed-sets each with 5 items for a total of 10 sentences. The PSI sentences also come in two formats, I and II, allowing the clinician to account for the age, vocabulary, and language skills of the child. Format I recordings were designed to be developmentally appropriate for children aged 3 to 5 years using the carrier phrase, "show me," prior to each sentence. Format II recordings were developed for children aged 5 years and older, and simply contain the sentence stimuli. As with the PSI words, the child is instructed to the point to the picture corresponding to the sentence.

Speech-Recognition Test Materials in Older Children

STUDENTS-HUB.com

Word Recognition: >3 Years

The MLNT and LNT (Kirk, Pisoni, & Osberger, 1995) were both developed with the Neighborhood Activation Model (Luce & Pisoni, 1998), which considers both word frequency and lexical density in spoken word recognition. See Chapter 3 for greater detail regarding construction of the MLNT and LNT. The MLNT lists includes 12 words each that can scored both in terms of whole word accuracy as well as phoneme accuracy. The MLNT includes 2 lexically easy and 2 lexically hard lists. The LNT list includes 25 words each that can also be scored in terms of whole word and phoneme accuracy. Similar to the MLNT, the LNT includes two lexically easy and two lexically hard lists. Both the MLNT and LNT recordings include single speaker tracks as well as multi-speaker tracks—most clinics use the single speaker tracks for assessment purposes.

For older children who are capable of completing more complex word recognition tasks—typically 5 years or older—the next recommended measure is monosyllabic word recognition with the CNC word lists (Peterson & Lehiste, 1962)—which is also used for assessment of adult cochlear implant users as outlined by the MSTB. The CNC test includes ten 50-word lists of equivalent intelligibility. The CNC recordings contain a single male talker using the carrier phrase "ready" prior to the target word. This carrier phrase serves as an effective orienting tool for a child who may be easily distracted. As with other word tasks, CNC words are generally scored both for whole word and phoneme accuracy.

Open-Set Sentence Recognition: 3+ Years

The BKB sentence corpus recommended for use in children uses the split sentence tracks from the BKB-SIN (Etymotic, 2005), which includes 16 sentence lists, each with 50 to 62 key words. The BKB sentences are spoken by a single male speaker using the carrier word "ready" prior to each sentence. The BKB sentences presented in quiet can be scored as overall percent key words repeated correctly. The pediatric AzBio sentences (Spahr et al., 2014), also commonly referred to as the "BabyBio" test, includes 16 lists of equivalent difficulty, each with 20 unique sentences spoken by a single female talker. Sentence length ranges from 3 to 12 words and are scored as overall percent words repeated correctly.

Uploaded By: tuka abuzneid

Speech Recognition in Noise

Assessing speech recognition in noise is recommended by the PMSTB as children are rarely in quiet listening environments (Crukley, Scollie, &

Parsa, 2011). The PMSTB recommends administration of both the Pediatric AzBio (BabyBio) sentences in noise as well as the BKB-SIN as the former uses a fixed SNR and the latter uses a quasi-adaptive SNR. If a child scores above 80% on the BabyBio sentences in quiet, BabyBio sentences in noise are the next recommended assessment. BabyBio sentences in noise are recommended for presentation at 65 dB SPL in a +5 dB SNR to increase the ecological validity of the assessment (Pearsons et al., 1977; Smeds, Wolters, & Rung, 2015). That is, in the presence of noise levels typically encountered in realistic listening environments, speakers are able to sustain vocal levels consistent with a maximum SNR of +5 dB SNR.

As discussed throughout this book, more important than the individual protocol and metrics themselves, is that all clinicians at an implant center are following the same protocol. Protocol adherence allows each implant program to generate its own normative data for patient outcomes, which significantly aids patient counseling and clinical decision-making. Protocol adherence and the resultant data provide clinics with the information needed to compare its outcomes to average patient performance in the literature as well as to provide data-driven counseling regarding additional interventions and provide guidance about whether a patient is performing as expected. Further, because most implant programs have multiple clinicians, adherence to clinical protocols along with the use of recorded stimuli will allow for clinician substitution without sacrificing assessment accuracy.

Assessing postoperative speech recognition for pediatric implant patients will be undertaken on a metric-by-metric basis, as we can never be certain how long a child will remain a cooperative participant. For this reason, it is recommended that each clinic adopt the "priority protocol" as outlined in the PMSTB for assessing speech recognition at each visit. This PMSTB priority protocol, as outlined in Figure 8–2, specifies not only the metrics to be used, but the order of administration (Uhler et al., 2017). This means that if time allows for only one test to be completed, the same type of test would be completed for all patients regardless of age, development, or clinician. If additional time allowed *and* the child's level of cooperation afforded further testing, the next metric in the priority protocol would be administered. This way, at a very minimum, a cochlear implant program would have the same information from each child over time—even if only a single metric could be administered.

Figure 8–2 displays the PMSTB protocol for pediatric assessment of auditory skills and speech recognition. The priority of metrics progresses from left to right as follows:

- parental questionnaires for the youngest patients
- phonemic discrimination via VRISD
- pattern perception via ESP
- spondee recognition via ESP
- monosyllabic words first via ESP followed by PSI, MLNT, LNT, and CNC, depending on the developmental abilities of the child
- sentence recognition in quiet first via PSI sentences followed by BKB sentences (BKB-SIN channel A on the split track recording), then BabyBio sentences, depending on the developmental abilities of the child
- sentence recognition in noise first via BKB-SIN followed by BabyBio sentences at +5 dB SNR

As described above, within a given category, a clinician would begin with the developmentally appropriate metric. For example, if you have been following a child over time and know that she is capable of completing open-set word testing, then there would be no need to begin with ESP pattern perception of spondee tests. Despite being a waste of precious assessment time, any information gleaned would be completely inconsistent with the child's realistic auditory capabilities and runs the risk of inflating the child's performance. On the other end of the spectrum, if you have a patient with limited auditory skills, delayed development and have never administered ESP pattern perception, then it would be a futile effort to first attempt speech recognition assessment using a difficult metric such as LNT monosyllables.

As shown in Figure 8–2 there are *nonspeech* measures that may be used for postoperative assessment of children with limited skills for which assessment of auditory discrimination/detection may be the goal. VRISD affords an

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com

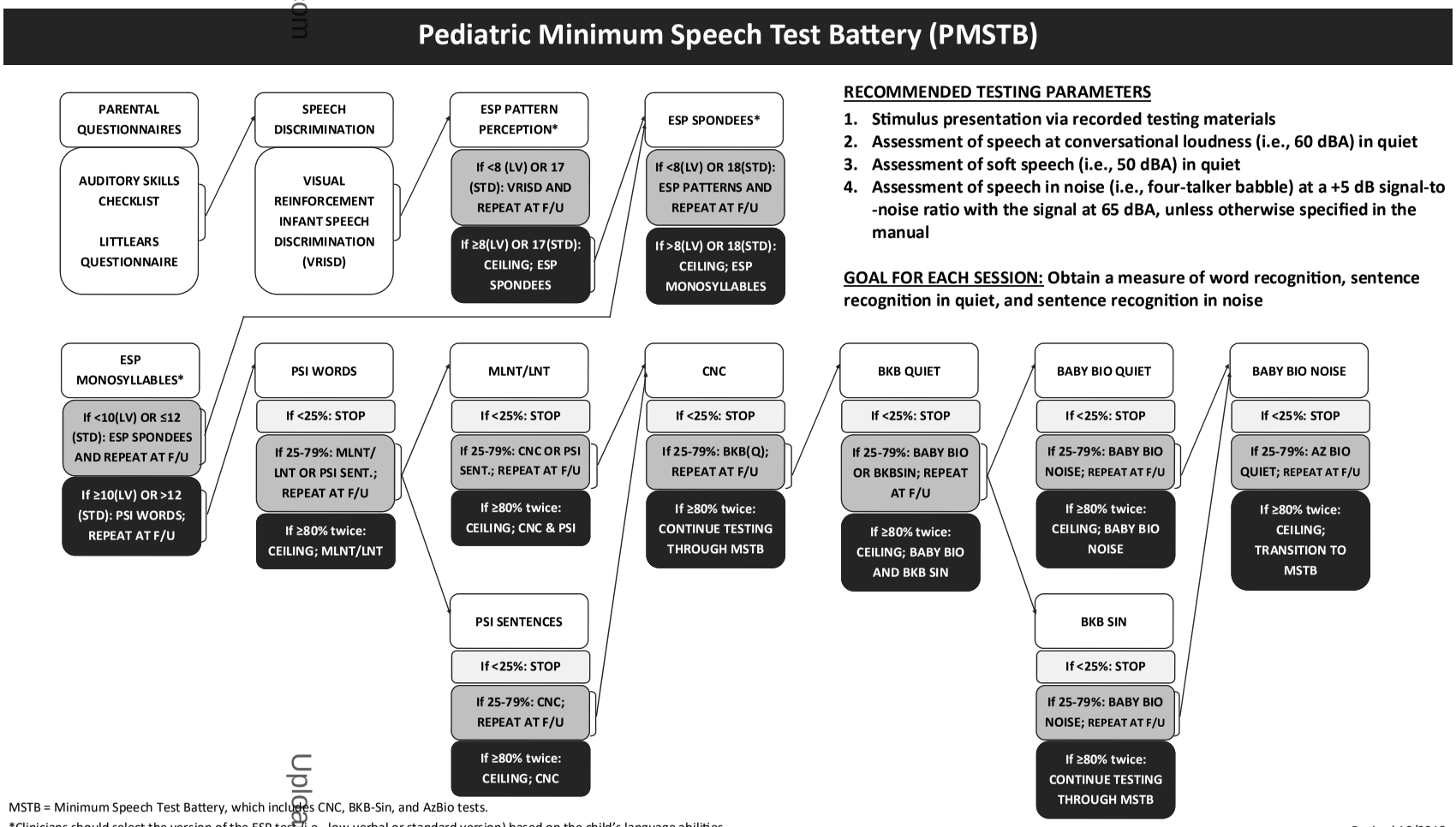


FIGURE 8–2. PMSTB protocol for speech recognition testing with pediatric implant recipients. Copyright © 2019 American Academy of Audiology. Reprinted by permission.

Uploaded By: tuka abuzneid

STUDENTS-HUB.com

Pediatric Minimum Speech Test Battery (PMSTB)

Device set-up	Conversational speech in quiet (60 dBA)	Low level in quiet (50 dBA)	Conversational speech in noise (65 dBA,+5 dB SNR)
Individual ear	X	X	X
Bilateral/ bimodal	X	X	X
Device + FM/DM			X

Scores ≤ 25% → • TOO DIFFICULT • Proceed with a simpler task

Scores 26-79% correct → • CHALLENGING • Repeat task at next test session

Scores ≥80% correct (2x) → • MASTERY • Proceed to the next level of difficulty

Duration of device use	Device type	
	Hearing aid	Cochlear implant
0 to 1 year	Every 3 months	Every 2-3 months
1 to 2 years	Every 3 months	Every 6 months
2 to 3 years	Every 3 months	Every 6 months
3 to 5 years	Every 6 months	Every 12 months
> 5 years	Every 12 months	Every 12 months

Revised 10/2018

Age (mos.)	Receptive language	Expressive language	Appropriate speech perception tests									
			Parent report	VRISD	SRT	ESP (LV)	PSI	ESP (Std), PSI	MLNT	LNT, CNC	BKB, BKB-SIN	BABY BIO
6-12	Single words; short phrases	N/A	X	X								
12-18	Short phrases, body parts	Single words	X	X	X							
18-24	Follows 2-part instruc-tions	Single words	X	X	X							
24-36	Follows 2-part instruc-tions	2-3 word combinations		X	X	X	X					
36-48	Follows 3-part instruc-tions	3-word sentences					X	X	X			
48-60	Follows sim-ple instruc-tions	3- to 5-word sentences							X	X		
> 60	Follows 3-part commands	Mostly correct gram-mar								X	X	X

FIGURE 8–2. *continued*

Uploaded By: tuka abuzneid

assessment of phonemic discrimination for infants from approximately 6 months up to 24 months of age (Uhler et al., 2015, 2018, 2011) and can therefore serve as a highly valuable tool validating implant programming. The low-verbal version of the ESP; (Moog & Geers, 1990)] focuses on pattern perception of sounds and words differing by number of syllables and word stress. Both VRISD and low-verbal ESP are suitable for postoperative assessment for children with limited auditory skills.

Closed-Set Measures of Word and Sentence Recognition

Closed-set tests include a limited set of possible choices for which a verbal response is not required. The ESP standard version for word recognition is a closed-set task of word recognition recommended for children aged 2 to 5 years, depending on the developmental level of the child. The ESP standard version includes two sub-tests including spondee and monosyllabic word identification, respectively. Both the spondee and monosyllabic subtests require that the child select 1 out of 12 color pictures corresponding to the spoken word. The 12 words are presented twice for a given run corresponding to a total possible of 24 correct words. ESP spondees and then monosyllables are recommended for administration following achievement of ceiling performance for ESP pattern perception.

The Pediatric Speech Intelligibility (PSI; Jerger & Jerger, 1984) word test is next in the PMSTB protocol following demonstration of ceiling performance for ESP monosyllables. The PSI word test can be used for children as young as 3 years up to approximately 7 years of age as the corpus was developed from actual responses of children aged 3 to 6 years with normal hearing in response to picture prompts (Jerger, Lewis, Hawkins, & Jerger, 1980). The PSI word task is administered by use of a carrier phrase "show me" followed by the target word. Children are instructed that they will hear a man say, "show me" and that the child should point to the picture that matches the word. Older children can simply repeat the target word. The PSI word test includes 20 words presented on 5 picture cards each containing 4 pictures.

Should a child demonstrate ceiling-level performance (≥80%) on the PSI word test across two separate assessment time points, the PSI sentence test is the next and last option in the PMSTB protocol for closed-set tasks. The PSI sentence test includes 10 sentences arranged as two different closed-set items each containing 5 sentences. As with the PSI words, the PSI sentences were developed from actual responses of children aged 3 to 6 years with normal hearing in response to picture prompts (Jerger et al., 1980). The PSI sentence test was recorded with two formats differing in carrier phrase prior to sentence delivery. Format I uses the carrier phrase "show me" prior to sentence delivery whereas Format II omits the use of the carrier phrase. The use of Format I is better suited to younger children (<5 years) whereas Format II is more appropriate for older school-aged children (5+ years). See the PMSTB manual for greater detail regarding PSI test training and administration (Uhler et al., 2017).

There are other measures of pediatric speech recognition that while not included in the PMSTB, may provide an interactive, game-like experience for children who are increasingly tech savvy. The Children's Realistic Intelligibility of Speech Perception (CRISP) and the CRISP Jr. were developed at the University of Wisconsin Madison in the laboratory of Dr. Ruth Litovsky. The CRISP is considered most appropriate for children aged 4 to 7 years. The CRISP stimuli include a closed set of 25 spondees and the level of the spondees is varied adaptively to achieve a speech reception threshold (SRT). The CRISP Jr. (Garadat & Litovsky, 2007) is a variation of the CRISP that is more appropriate for children aged 2.5 to 5 years. Crisp Jr. stimuli include a closed set of 16 words with the names of objects and/or body parts. The CRISP can be administered in a manual scoring method or via computer game interaction with the patient. The speech stimuli can be presented in quiet or in the presence of a background noise originating from the same source as the target or from a separate loudspeaker. With the spatial separation of the spondees and the noise, the CRISP and CRISP Jr. can also provide an estimate of the spatial release from masking; however, spatial release from masking is not currently a task that is typically assessed clinically, though it

STUDENTSHUB.com Uploaded By: tuka abuzneid

could certainly provide clinical guidance regarding effectiveness of intervention (e.g., cochlear implant, bimodal hearing, bilateral implantation) and be potentially useful for determining bilateral implant candidacy, as well as determining the need for FM/DM system outside the classroom.

Open-Set Measures of Word Recognition

The PMSTB lists a number of open-set measures that evaluate word recognition that are appropriate for pediatric use at different levels of development, including the Multisyllabic lexical neighborhood test (MLNT; Kirk et al., 1995), the Lexical Neighborhood Test (LNT; Kirk et al., 1995), and the Consonant Nucleus Consonant (CNC; Peterson & Lehiste, 1962) words. As described in Chapter 3, both MLNT and LNT were developed with the Neighborhood Activation Model (Luce & Pisoni, 1998; Luce, 1986; Luce, Pisoni, & Goldinger, 1990), considering both word frequency and lexical density in spoken word recognition. Word frequency references how often a particular word occurs in spoken language for a given age range. Lexical density references the number of phonemically similar words to the target word (Greenberg & Jenkins, 1964; Landauer & Streeter, 1973). The term "lexical neighbor" refers to a word differing by one phoneme such as pit, hot, hat, his, hid, and sit being neighbors of the target word "hit." Target words that have a large number of lexical neighbors are said to arise from "dense" lexical neighborhoods; in contrast, words with few lexical neighbors are said to arise from "sparse" lexical neighborhoods. As such, the MLNT and LNT each have two versions: lexically easy and lexically hard. The lexically easy MLNT and LNT lists include high-frequency words from sparse lexical neighborhoods. The lexically hard MLNT and LNT lists include lower frequency words from dense lexical neighborhoods (Luce, 1986; Luce et al, 1990; Luce & Pisoni, 1998).

The MLNT word lists are considered the least complex of the open-set word tests in the PMSTB as they include multisyllabic words that are generally easiest for children to understand and correctly repeat, as compared to monosyllables. The MLNT word lists include two lexically easy and two lexically difficult lists, each with 12 words. MLNT would be attempted following documentation of ceiling-level performance for PSI words (see Figure 8–2).

Progressing from MLNT to LNT monosyllabic word lists would be the next step in the PMSTB protocol following documentation of ceiling-level performance (≥80%) for MLNT words across two time points. The LNT word lists also include two lexically easy and two lexically difficult lists each with 25 words. Important to note here is that there are concerns about the number of available words lists for MLNT and LNT as we assess multiple postoperative listening conditions over time. However, once a child demonstrates ≥80% performance for LNT across two test sessions, the next test in the PMSTB protocol progression would be CNC words, which are included in both the PMSTB and adult MSTB. The CNC word lists include ten lists of 50 words. Clinicians who have administered the CNC test to children can attest that the carrier phrase "ready" renders this test easier than might be expected for pediatric implant recipients. The biggest concern with administration of the CNC test for children is the language level of the included words, some of which may be considered antiquated and having low word frequency in American English, such as lathe, thatch, and salve.

Open-Set Measures of Sentence Recognition

There are a number of recorded, open-set sentence recognition metrics that are included in the PMSTB protocol and thus appropriate for assessment of a child's auditory and speech perception profile. The PMSTB includes the following open-set sentence tests: Bamford-Kowal-Bench (BKB) sentences, pediatric AzBio sentences, and finally the AzBio sentences. The BKB sentences as recommended on the PMSTB originate from the split-track recordings of the BKB-SIN test (Etymotic, 2005). The BKB lists—as included in the BKB-SIN test—include 16 sentence lists, each with 50 to 62 key words. The BKB sentences are spoken by a single male speaker using a carrier phrase "ready" prior to each sentence. The BKB sentences as listed in the PMSTB protocol are the first introduction to sentence recognition for children and are to be presented in quiet following word recognition

STUDENTS-HUB.com Uploaded By: tuka abuzneid

testing. BKB sentence recognition would be scored as overall percent correct of the listed key words.

The pediatric AzBio sentences (Spahr et al., 2014)—commonly referred to as the "BabyBio" sentences—include 16 lists of equivalent difficulty, each with 20 unique sentences. Sentences range from 3 to 12 words and are scored as overall percent words repeated correctly. Unlike the majority of the other recorded stimuli, BabyBio sentences are spoken by a single female talker. According to the PMSTB, BabyBio sentences are to be presented following documentation of ceiling-level performance (≥80%) on BKB sentences across two testing sessions (see Figure 8–2).

Finally, should a child exhibit ≥80% performance at two time points, then we progress to the open-set sentences referenced in the adult MSTB (MSTB, 2011). As described in Chapters 2 and 7, AzBio sentences (Spahr et al., 2012) are currently used for both candidacy determination and postoperative assessment of speech recognition for adult cochlear implant recipients. We have a number of children who have exhibited ceiling performance for BabyBio sentences, necessitating use of the AzBio corpus. Though the language complexity of the AzBio sentences is consistent with a 4th grade level, it should be noted that some of the AzBio sentences contain adult themes and are thus not suitable for children. Some example sentences include, "I'll have a cranberry and vodka please," and, "He put a horse's head in their bed." As such, out of the 33 sentence lists in the original AzBio corpus, the following lists are considered to be most pediatric friendly: 2, 4, 7, 8, 9, 12, 13, 15, 17, 21, 24, 28, 30, and 33.

Sentence Recognition in Noise

As mentioned in Chapter 3, assessing speech recognition in noise is recommended as children are rarely in quiet listening environments. Educational acoustic research has shown that occupied classroom noise can range from 48 to over 70 dBA with the mean level approximately 65 dBA for an early elementary classroom (Bess, Sinclair, & Riggs, 1984; Crukley et al., 2011; Finitzo-Hieber, 1988; L. Nober & E, Nober, 1975; Sanders, 1965). Considering a child's listening environment both inside and outside the classroom, research has shown that Leq 24-hr measurement averages 87.3 dBA for all students and 95.5 dBA for fifth graders (Clark & Govett, 1995). Given that a child's everyday listening environment is much noisier than even that encountered by the typical adult, it follows that we should be assessing postoperative speech recognition in the presence of background noise. In fact, without speech in noise testing, we cannot fully assess a child's auditory capabilities in a typical everyday listening environment.

The PMSTB recommends assessment of speech recognition in noise using the Pediatric AzBio (BabyBio) sentences as well as the BKB-SIN. The BabyBio sentences are recommended for presentation at 65 dB SPL in a +5 dB SNR to increase the ecological validity of the assessment. That is, typical noise levels encountered in typical, everyday listening environments are in the range of 60 to 70 dBA (Crukley et al., 2011; Lebo et al., 1994; Pearsons et al., 1977) and in the presence of these noise levels, talkers are able to sustain speaking levels consistent with +3 to +5 dB SNR (Pearsons et al., 1977; Smeds et al., 2015). The PMSTB does not recommend assessment of speech in noise using more favorable SNRs, such as +10 dB, as this represents an unlikely acoustic scenario that our patients will not often encounter. However, clinical decisions are sometimes made to assess performance at multiple SNRs, particularly for children who may exhibit extremely poor performance at +5 dB even if only to allow a child to successful complete the testing in noise.

As discussed in Chapters 2 and 7, the BKB-SIN test is a pseudo-adaptive metric in that the recorded multitalker babble automatically increases by 3 dB with each fixed-level sentence in the list. The BKB-SIN test provides both a raw score, SNR-50, and an estimate of SNR loss. The SNR-50 provides the SNR required for the listener to achieve approximately 50% correct and is based on classic speech perception research describing the determination of speech reception thresholds (Martin & Stauffer, 1975; Tillman & Olsen, 1973). The SNR loss describes the listener's deficit relative to normative data for age-matched subjects with normal hearing. Thus, the SNR loss provides information about how a child is able to perceive speech in noise relative to her peers with normal hearing. As with BabyBio sentences in noise, BKB-SIN speech stimuli should be presented at 65 dBA.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Testing Conditions

The testing conditions to be assessed in the postoperative assessment period will vary depending on the goal of the appointment. Individual ear assessment is desired for all implanted ears to ensure optimal audibility and speech recognition abilities for each ear independently. However, since children are rarely listening in a single ear condition—except for perhaps during therapy sessions—assessing the bilateral, best-aided condition also makes practical sense.

The PMSTB recommends assessment individual ear performance as well as the bilateral best-aided condition for a given measure in the assessment protocol before progressing to the next measure. For example, if you were seeing a 5-year-old child who uses a bimodal hearing configuration for her 6-month post-activation appointment, you would start with the developmentally appropriate word recognition task, which in this case would likely be LNT or CNC words. You would present LNT or CNC words first at 60 dBA and assess implant-alone performance (occluding the nonimplanted ear) followed by the bimodal condition before progressing to low-level presentation (50 dBA) of LNT or CNC words (in the implant alone condition followed by the bimodal condition). If time allowed, and the child was still cooperative, you could then progress to sentence recognition in quiet in the implant-alone condition. Table 8–1 displays the recommended testing conditions for children as outlined by the PMSTB. Because children may not remain cooperative throughout an entire testing session, it will likely take multiple visits—spanning months to years—to obtain a complete audiologic profile of postoperative speech understanding performance. This is expected and it is with this in mind that the PMSTB protocol and recommended testing schedule were developed.

Philosophy Driving Postoperative Speech Recognition

As counseled by Madell (2013), the purpose of speech recognition testing is not to allow a child to obtain the best possible score. Rather our goal should be to assess the effectiveness of the chosen rehabilitation strategy (conventional amplification vs. cochlear implants), the hearing modality (bimodal vs. bilateral), as well as evaluating the efficacy of the current technology settings. Furthermore, we should be able to use the information gathered from postoperative speech recognition testing to guide future habilitation, recommendations for scheduling of subsequent follow-up visits, programming modifications, as well as assisting educational recommendations, such as technological needs in the classroom. Thus, we should remain cognizant of these points before entering the sound booth and orienting our patient and her parents about the speech recognition tasks and the purpose of the assessment. Appropriate preassessment counseling is critical to maximize the likelihood that a child will provide her best efforts, particularly in difficult listening conditions (e.g., low-level speech and speech in noise) and to ensure that she and her parents understand that the testing conditions are necessarily difficult. That is, we do not expect perfect performance, which allows us to use the same measures over time to document performance gains.

Parental Questionnaires for Assessing Postoperative Auditory Skills

Auditory skills development for younger children is most likely gauged via auditory questionnaire data, parental report, and speech/language assessment. This will particularly be true for the youngest implant recipients (<12 months up to 2 years) for which immediate postoperative assessment of speech understanding will not be possible using conventional metrics, as displayed in Figure 8–2. For a detailed description of the most widely used pediatric auditory questionnaires, see Table 3–2 in Chapter 3. It is recommended that regardless of the progress made immediately post activation, that we administer the same questionnaires that were administered immediately preimplant so that we are able to describe the relative benefit derived from cochlear implantation in a pre- vs postimplant comparison. Over time, as a child's auditory skills rapidly mature, we will adapt our questionnaire administration to be consistent with the child's auditory developmental status.

At present, the PMSTB only lists the LittlEARS and ASC as parental questionnaires for

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 8–1. PMSTB Recommended Listening Conditions for Speech Recognition Testing

Measure	*Calibrated presentation level*	*Listening conditions tested*
1. Speech in quiet Conversational level	60 dBA	Individual ear(s) then Bilateral, best-aided (e.g., bimodal or bilateral implants)
2. Speech in quiet Low level	50 dBA	Individual ear(s) then Bilateral, best-aided
3. Speech in noise	Speech: 65 dBA Noise: 60 dBA	Individual ear(s) then Bilateral, best-aided

assessing auditory skills in the youngest implant candidates and recipients. The reason is that the purpose of the PMSTB protocol is to assess speech recognition and as a child ages and matures, most are able to complete behavioral testing. Even if a child is able to complete behavioral speech recognition testing, there is still value in obtaining subjective data from patient and parental report. There are a number of validated questionnaires and subjective measures that were designed for gauging skills and communication difficulties for children with hearing loss (see Chapter 3, Table 3–2). Individual clinics will determine which auditory questionnaires best meet the needs of their patient population and their families. However, more important than the actual questionnaires used, is the goal that clinicians within a given program be consistent across all patients.

THE ROLE OF THE SOCIAL WORKER AND/OR PSYCHOLOGIST IN THE POSTOPERATIVE PERIOD

STUDENTSWORKER Uploaded By: tuka abuzneid

The role of the social worker and/or psychologist in the postoperative period tends to be less critical than that experienced preoperatively. Social workers are able to provide counseling and support for families in in terms of finances as related to medical care surrounding aural habilitation—particularly should issues with insurance coverage arise. Families may be unaware of the financial resources available to them for insurance coverage of medical care, therapy, and assistive listening devices. Social workers not only provide this information, but also help provide access to the appropriate paperwork and help families navigate through the application processes. In some cases, social workers are able to help families coordinate medical and therapy appointments and review the past and current schedule of appointments to ensure that all medical specialties and evaluations have been made available to the family.

Psychological evaluations may come into play during the postoperative period for those families of children not making expected auditory progress following implantation. For children implanted as infants and young toddlers, any future issues surrounding developmental delay may not yet be known at the time of implantation. Should a child fail to make expected postimplant progress despite adherence to the recommended therapy schedule and full-time usage of the implant (i.e., wearing the sound processor all waking hours), developmental psychological evaluation may be recommended by the cochlear implant team (Figure 8–3).

MEDICAL/SURGICAL MANAGEMENT OF THE PEDIATRIC IMPLANT RECIPIENT

The cochlear implant surgeon—typically an otologist or neuro-otologist—plays an obvious critical role in the preoperative determination of implant candidacy. Otologists also play a critical role in

the *postoperative* management of all implant recipients. It is customary for surgeons to see implant patients around the time of the initial activation for postoperative check of incision, scalp flap, and reconciliation of surgical related symptoms (such as dizziness, pain, etc.). This postoperative check does not mark the end of the surgeon's management of the implant patient. The otologist and his/her medical team will also ensure that all cochlear implant candidates are up to date on their immunizations not only prior to cochlear implantation but also over time as the Centers for Disease Control (CDC) updates the recommended booster protocol for age-specific pneumococcal vaccinations.

From an insurance coverage perspective, most insurance plans require patients to obtain a physician order for audiologic and speech/language follow up and programming. In order for the physician to be in compliance, he/she will need to maintain medical oversight of a patient's care. Notwithstanding the insurance requirement for signed physician order for regular audiologic management, implant recipients remain under the medical care of their implanting surgeons, and should thus be seen regularly for otoscopic and postauricular evaluation. Many otologists continue to see their pediatric implant patients on an annual or biennial basis as standard practice. In addition to this standard practice, audiologists will undoubtedly be closely acquainted with the overall otoscopic and postauricular health of implant patients and will refer for medical consult in cases of redness, irritation, skin breakdown, electrode/device extrusion or any other physical or suspected device failure concern related to the implant that is outside the audiologists' scope of practice.



FIGURE 8–3. Otologic surgeon Dr. Labadie completes otoscopy on a 3-year-old with left cochlear implant.

CONCLUSION

Cochlear implants have the potential to change the course of a child's life, allowing for normal development of speech, language, and literacy. Even for those children not able to achieve an auditory/oral approach to communication, cochlear implants provide sound awareness that increases safety and quality of life for the recipient. In order to do our part to ensure that the audiologic management of the technology is providing the child with the highest auditory potential, we must diligently seek to assess postoperative performance for audibility, auditory skills progress, as well as speech understanding skills. For further information regarding the aspects of postoperative assessment related to the speech/language pathologist (SLP), auditory verbal therapist (AVT), and deaf educator please see Chapter 9. The interdisciplinary cochlear implant team offers patients the highest level of care needed to excel and progress through the postoperative process. As mentioned previously, obtaining cochlear implants is only the first step in the journey, as the hardest work occurs *after* the surgery.

Postoperative assessment of outcomes is a vital component of the best-practices management for implant audiologists working with children. Postoperative assessment is not limited to the auditory questionnaire data, or obtaining speech

STUDENTS-HUB.com Uploaded By: tuka abuzneid

and language records from the child's SLP, AVT, and deaf educator. Audiologists, SLPs, AVTs and deaf educators must make a concerted effort to work as a management "team" to provide a child with the best chances for maximizing his or her auditory potential. Theresa Caraway (2012) has used the term "flexible team boundaries" to describe a team building approach for a child's audiologist, SLP/AVT, and deaf educator to integrate the management of a child's technology, therapy schedule, habilitation options, and educational placement recommendations (Caraway, 2012). We are all working toward the same goal, but often fail to work together for reasons that may simply be due to the fact that we work in different physical locations.

Each cochlear implant center has its own needs, patients, and culture. Thus, it is up to each individual center and its team members to develop a pediatric protocol for postoperative assessment, and to define its own team boundaries for patient management. More important than the actual protocol, is *adherence to the protocol* in order for the team to generate program- specific norms and for the longitudinal assessment of patient performance. Postoperative data obtained over the long term will provide us with valuable clinical information regarding variability in patient performance, need for programming adjustments, equipment malfunction, and recommendations for additional assistive technology, and so forth. It is a given that over time, the individual metrics used in the protocol will change, just as we've seen the evolution of the adult MSTB over the past two decades, and the relatively new PMSTB for pediatric assessment. We will be ready for evolutionary changes and will be able to document the relationship between our patients' performance on previous measures with future measures, only if we adhere to our current protocols for postoperative assessment of performance.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

American Academy of Audiology. (2003). Pediatric amplification protocol. Retrieved May 2, 2012, from http://www.audiology.org

Bess, F. H., Sinclair, J. S., & Riggs, D. (1984). Group amplification in schools for the hearing impaired. *Ear and Hearing, 5*, 138–144.

Boothroyd, A. (1984). Auditory perception of speech contrasts by subjects with sensorineural hearingloss. *Journal of Speech and Hearing Research, 27*, 134–144.

Brown, R. F., Hullar, T. E., Cadieux, J. H., & Chole, R. A. (2010). Residual hearing preservation after pediatric cochlear implantation. *Otology & Neurotology, 31*(8), 1221.

Caraway, T. (2012). *Play it by ear: Strategies and techniques to improve outcomes for children with hearing loss. Controversial issues in pediatric audiology*. New York, NY.

Carhart, R. (1946). Monitored live-voice as a test of auditory acuity. *Journal of the Acoustical Society of America, 17*, 339–349.

Carlson, M. L., Driscoll, C. L. W., Gifford, R. H., Service, G. J., Tombers, N. M., Hughes-Borst, B. J., . . . Beatty, C. W. (2011). Implications of minimizing trauma during conventional cochlear implantation. *Otology and Neurotology, 32*(6), 962. https://doi.org/10.1097/MAO.0b013e3182204526

Carlson, M. L., Patel, N. S., Tombers, N. M., DeJong, M. D., Breneman, A. I., Neff, B. A., & Driscoll, C. L. W. (2017). Hearing preservation in pediatric cochlear implantation. *Otology & Neurotology, 38*(6), e128–133.

Clark, W. W., & Govett, S. B. (1995). School-related noise exposure in children. *Proceedings of the 18 the Midwinter Meeting of the Association for Research in Otolaryngology* (p. 197).

Cornelisse, L., Seewald, R., & Jamieson, D. (1995). The input/output formula: A theoretical approach to the fitting of personal amplification devices. *Journal of the Acoustical Society of America, 97*(3), 1854.

Crukley, J., Scollie, S., & Parsa, V. (2011). An exploration of non-quiet listening at school. *Journal of Educational Audiology, 17*, 23–35.

Dedhia, K., Worman, T., Meredith, M. A., & Rubinstein, J. T. (2016). Patterns of long-term hearing loss in hearing preservation cochlear implant surgery. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 37*(5), 478–486. https://doi.org/10.1097/MAO.0000000000001011

Eilers, R. E., Morse, P. A., Gavin, W. J., & Oller, D. K. (1981). Discrimination of voice onset time in infancy. *Journal of the Acoustical Society of America, 70*, 955–965.

Eilers, R. E., Wilson, W. R., & Moore, J. M. (1977). Developmental changes in speech discrimination in infants. *Journal of the Acoustical Society of America, 20*, 766–780.

Etymotic, (2005). *BKB-SIN Test. Speech-in-Noise Test Version 1.03*. Retrieved from www.etymotic.com

Finitzo-Hieber, T. (1988). Classroom acoustics. In Editors? *Auditory disorders in school children* (2nd ed.) (pp. 221–223). New York, NY: Thieme-Stratton.

Garadat, S. N., & Litovsky, R. Y. (2007). Speech intelligibility in free field: Spatial unmasking in preschool children. *Journal of the Acoustical Society of America, 121*(2), 1047–1055.

Greenberg, J. H., & Jenkins, J. J. (1964). Studies in the psychological correlates of the sound system of American English. *Word, 20*, 157–177.

Jerger, S., Lewis, S., Hawkins, J., & Jerger, J. (1980). Pediatric Speech Intelligibility Test. I. Generation of test material. *International Journal of Pediatric Otorhinolaryngology, 2*, 217–230.

Jerger, S. & Jerger, J. (1984). Pediatric Speech Intelligibility Test. Auditec of St. Louis, St. Louis, MO.

Kirk, K. I., Pisoni, D. B., & Osberger, M. J. (1995). Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear and Hearing, 16*, 470–481.

Kruel, E., Bell, D., & Nixon, J. (1969). Factors affecting speech discrimination test difficulty. *Journal of Speech and Hearing Research, 12*, 281–287.

Kuthubutheen, J., Hedne, C. N., Krishnaswamy, J., & Rajan, G. P. (2012). A case series of paediatric hearing preservation cochlear implantation: A new treatment modality for children with drug-induced or congenital partial deafness. *Audiology and Neurotology, 17*(5), 321–330.

Landauer, T. K., & Streeter, L. A. (1973). Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *Journal of Verbal Learning and Verbal Behavior, 12*(2), 119–131.

Lebo, C. P., Smith, M. F. W., Mosher, E. R., Jelonek, S. J., Schwind, D. R., Decker, K. E., . . . Kurz, P. L. (1994). Restaurant noise, hearing loss, and hearing aids. *Western Journal of Medicine, 161*(1), 45–49.

Luce, P. A. (1986). Neighborhoods of Words in the Mental Lexicon.

Luce, P. . A., & Pisoni, D. B. (1998). Recognizing spoken words: the neighborhood activation model. *Ear & Hearing, 19*, 1–36.

Luce, P. A., Pisoni, D. B., & Goldinger, S. (1990). Similarity neighborhoods of spoken words. In *Cognitive models of speech processing: Psycholinguistic and computational perspectives* (pp. 122–147). Cambridge, MA: The MIT Press.

Mackersie, C. L. (2002). Tests of speech perception abilities. *Current Opinion in Otolaryngology & Head and Neck Surgery, 10*, 392–397.

Madell, J. R. (2013). Evaluation of speech perception in infants and children. In J. R. Madell & C. Flexer, *Pediatric audiology: diagnosis, technology, and management* (2nd ed.). New York, NY: Thieme.

Martin, F. N., & Stauffer, M. L. (1975). A modification of the Tillman-Olsen method for obtaining the speech reception threshold. *Journal of Speech and Hearing Disorders, 40*(1), 25–28.

Moog, J. S., & Geers, A. (1990). *Early speech perception test for profoundly hearing-impaired children*. St. Louis, MO: Central Institute for the Deaf.

MSTB. (2011). *Minimum Speech Test Battery For Adult Cochlear Implant Users*. Retrieved from http://auditorypotential.com/MSTBfiles/MSTBManual 2011-06-20.pdf

Mueller, H. G., & Killion, M. C. (1990). An easy method for calculating the articulation index. *Hearing Journal, 43*, 1–4.

Nober, L. W., & Nober, E. H. (1975). Auditory discrimination of learning disabled children in quiet and classroom noise. *Journal of Learning Disabilities, 8*, 656–659.

Olsen, W. O. (1998). Average speech levels and spectra in various speaking/listening conditions: A summary of the Pearson, Bennett & Fidel Report. *American Journal of Audiology, 7*, 21–25.

Park, L. R., Teagle, H. F. B., Gagnon, E., Woodard, J., & Brown, K. D. (2018). Electric-Acoustic stimulation outcomes in children. *Ear and Hearing*, *40*, 849–857.

Pearsons, K. S., Bennett, R. L., & Fidell, S. (1977). *Speech levels in various noise environments. Report No. EPA-600/1-77-025*. Washington, DC.

Peterson, G. E., & Lehiste, I. (1962). Revised CNC lists for auditory tests. *Journal of Speech and Hearing Disorders, 27*, 62–72.

Rajan, G., Tavora-Vieira, D., Baumgartner, W. D., Godey, B., Müller, J., O'Driscoll, M., . . . van de Heyning, P. (2018). Hearing preservation cochlear implantation in children: The HEARRING Group consensus and practice guide. *Cochlear Implants International, 19*(1), 1–13.

Roland, J. T., Gantz, B. J., Waltzman, S. B., & Parkinson, A. J. (2016). United States multicenter clinical trial of the cochlear nucleus hybrid implant system. *Laryngoscope, 126*(1), 175–181. https://doi.org/10.1002/lary.25451

Sanders, D. (1965). Noise conditions in normal school classrooms. *Exceptional Child1, 31*, 344–353.

Scollie, S., Seewald, R., Cornelisse, L., Moodie, S., Bagatto, M., Laurnagaray, D., . . . Pumford, J. (2005). The desired sensation level multistage input/output algorithm. *Trends in Amplification, 9*(4), 159–197.

Seewald, R. C., Ross, M., & Spiro, M. K. (1985). Selecting amplification characteristics for young hearing-impaired children. *Ear and Hearing, 6*, 48–51.

STUDENTS-HUB.com Uploaded By: Iuka abuzneid

Skarzynski, H., & Lorens, A. (2010). Electric acoustic stimulation in children. *Advances in Oto-Rhino-Laryngology, 67*, 135–143.

Skarzynski, H., Matusiak, M., Furmanek, M., Pilka, A., Wlodarczyk, E., Oldak, M., & Skarzynski, P. H. (2018). Radiologic measurement of cochlea and hearing preservation rate using slim straight electrode (CI422) and round window approach. *Acta Otorhinolaryngologica Italica, 38*(5), 468–475.

Skarzynski, H., Matusiak, M., Lorens, A., Furmanek, M., Pilka, A., & Skarzynski, P. H. (2016). Preservation of cochlear structures and hearing when using the Nucleus Slim Straight (CI422) electrode in children. *Journal of Laryngology and Otology, 130*(4), 332–339. https://doi.org/10.1017/S0022215115003436

Skinner, M. W., Holden, L. K., Holden, T. A., & Demorest, M. E. (1999). Comparison of two methods for selecting minimum stimulation levels used in programming the Nucleus 22 cochlear implant. *Journal of Speech, Language, and Hearing Research, 42*, 814–828.

Skinner, M. W., Holden, L. K., Holden, T. A., Demorest, M. E., & Fourakis, M. S. (1997). Speech recognition at simulated soft, conversational, and raised-to-loud vocal efforts by adults with cochlear implants. *Journal of the Acoustical Society of America, 101*(6), 3766–3782.

Smeds, K., Wolters, F., & Rung, M. (2015). Estimation of signal-to-noise ratios in realistic sound scenarios. *Journal of the American Academy of Audiology, 26*(2), 183–196. https://doi.org/10.3766/jaaa.26.2.7

Spahr, A. J., Dorman, M. F., Litvak, L. M., Cook, S. J., Loiselle, L. M., Dejong, M. D., . . . Gifford, R. H. (2014). Development and validation of the Pediatric AzBio Sentence Lists. *Ear and Hearing, 35*(4). https://doi.org/10.1097/AUD.0000000000000031

Spahr, A. J., Dorman, M. F., Litvak, L. M., Van Wie, S., Gifford, R. H., Loizou, P. C., . . . Cook, S. (2012). Development and validation of the Azbios Sentence Lists. *Ear and Hearing, 33*(1), 112. https://doi.org/10.1097/AUD.0b013e31822c2549

Suhling, M. C., Majdani, O., Salcher, R., Leifholz, M., Buchner, A., Lesinski-Schiedat, A., & Lenarz, T. (2016). The impact of electrode array length on hearing preservation in cochlear implantation. *Otology & Neurotology, 37*(8), 1006–1015.

Tillman, T. W., & Olsen, W. O. (1973). Speech audiometry. In *Modern developments in audiology* (2nd ed.). New York, NY: Academic Press.

Uhler, K., Baca, R., Dudas, E., & Frederickson, T. (2015). Refining stimulus parameters in assessing infant speech perception using visual reinforcement infant speech discrimination: Sensation level. *Journal of the American Academy of Audiology, 26*(10), 807–814.

Uhler, K., Biever, A., & Gifford, R. H. (2016). Method of speech stimulus presentation impacts pediatric speech recognition monitored live voice versus recorded speech. *Otology & Neurotology, 37*, e70–e74.

Uhler, K., Gifford, R. H., Forsteer, J. E., Anderson, M., Tierney, E., Claycomb, S. D., & Werner, L. A. (2018). Refining stimulus parameters in assessing infant speech perception using visual reinforcement infant speech discrimination in infants with and without hearing loss: Presentation level. *Journal of the American Academy of Audiology, 29*(9), 847–854.

Uhler, K., Warner-Czyz, A., & Gifford, R. H. (2017). Pediatric Minimum Speech Test Battery. *Journal of the American Academy of Audiology, 28*(3), 232–247.

Uhler, K., Yosinaga-Itano, C., Gabbard, S. A., Rothpletz, A. M., & Jenkins, H. (2011). Longitudinal infant speech perception in young cochlear implant users. *Journal of the American Academy of Audiology, 22*(3), 129–142.

van Wieringer, A., & Wouters, J. (1999). Natural vowel and consonant recognition by Laura Cochlear implantees. *Ear & Hearing, 10*, 89–103.

Wanna, G. B., O'Connell, B. P., Francis, D. O., Gifford, R. H., Hunter, J. B., Holder, J. T., . . . Haynes, D. S. (2018). Predictive factors for short- and long-term hearing preservation in cochlear implantation with conventional-length electrodes. *Laryngoscope, 128*(2), 482–489.

Wolfe, J., Neumann, S., Schafer, E., Marsh, M., Wood, M., & Baker, R. S. (2017). Potential benefits of anintegrated electric-acoustic sound processor with children: A preliminary report. *Journal of the American Academy of Audiology, 28*(2), 127–140.

Woodson, E. A., Reiss, L. A. J., Turner, C. W., Gfeller, K., & Gantz, B. J. (2009). The hybrid cochlear implant: A review. *Cochlear Implants and Hearing Preservation, 67*, 125–134. https://doi.org/10.1159/000262604

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

9

Role of the Speech-Language Pathologist and Teacher of the Deaf in the Postoperative Assessment of Children

Emily Lund

INTRODUCTION

Speech-language pathologists (SLP), teachers of the deaf (TOD), and in some cases, other early interventionists (EI) play important roles in monitoring the progress of cochlear implant recipients. These professionals see children regularly and across various settings, and consequently, they are ideally positioned to collect data on children's performances over time. Information about a child's progress helps a rehabilitation team to answer one key question: Is the child making the expected amount of progress as a result of his or her cochlear implant?

As in preoperative assessment, it is imperative that a team evaluating postoperative outcomes of a child (or adult) with a cochlear implant understand the principles of monitoring progress. Additionally, professionals should understand the role of progress monitoring in future decisions that are made for a child with a cochlear implant.

This chapter (a) outlines the principles of progress monitoring and recommended schedule for postoperative assessment, (b) details popular assessment and therapeutic tools used by SLPs and other educators, and (c) discusses the roles of professionals, including SLPs and TODs, in the rehabilitation process.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

PRINCIPLES OF POSTOPERATIVE PROGRESS MONITORING

Progress-monitoring instruments are designed to give professionals periodic feedback about a

child's skill acquisition (Francis et al., 2008). Lack of access to sound prior to implantation can cause delays across many domains, including speech, language, and academic achievement; therefore, professionals evaluating postoperative outcomes need to consider the rate at which a child with a cochlear implant is acquiring new skills. Specifically, a team must answer the following questions: What is the child's rate of progress? Has the rate of progress changed following cochlear implantation? How does the child's progress compare to the rate expected by the cochlear implant team? Ideally, the team should answer these questions across several different domains, including speech production, language development, auditory functioning, and academic achievement.

To answer these questions, the rehabilitative team needs to agree on a regular postoperative assessment schedule. Ideally, a child who receives a cochlear implant should receive a comprehensive speech–language evaluation 6 and 12 months postimplant, and annually thereafter (Table 9–1). In addition, professionals on the team may wish to track progress with specific measures more frequently to establish a clear rate of growth. Once a child demonstrates age-appropriate speech, language, and/or academic skills with his or her implant, the team may decide to further alter or discontinue assessment within a specific domain.

Although many assessment instruments are available to a rehabilitative team, not all of these instruments are appropriate for progress monitoring. Norm-referenced measures are designed to identify a child's delays relative to other typically developing children; they should only be administered according to a restricted schedule

Table 9–1. Sample Timeline for Postoperative Assessment

Time Post-implantation	*Domains to Assess*	*Additional Decision Notes*
6 months	Auditory skills, speech production, language skills, academic knowledge	During this period, the team will want to use only criterion-referenced measures. If progress within the first 3 months appears insufficient to the team, additional assessments within a given domain may be completed at 9 months.
12 months	Auditory skills, speech production, language skills, academic knowledge	The team may use a combination of criterion-referenced and/or norm-referenced measures to determine (a) if the child is still delayed and (b) what is his or her rate or progress.
2 years	Auditory skills, speech production, language skills, academic knowledge	If the rate of progress was slower than the rehabilitation team predicted during the first year, progress-monitoring assessments may be given every 3 months or on a similar schedule.
3 years	Auditory skills, speech production, language skills, academic knowledge	During an annual assessment, if a child demonstrates age-appropriate skills in one domain (e.g., speech production), the team may decide to discontinue testing in that domain unless a parent, therapist, or teacher raises additional concerns.
Prior to IEP (Individualized Education Plan) qualifications	Auditory skills, speech production, language skills, academic knowledge	Before a child is initially evaluated or reevaluated for an IEP, the team should complete comprehensive testing composed primarily of norm-referenced measures to determine if the child's skills are exceptional.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

(i.e., only one time per year). Norm-referenced measures are not, therefore, ideal for measuring progress over a short period of time (e.g., weeks or months). Because criterion-referenced measures are designed to determine if a child has mastered a particular set of skills, some measures can be administered repeatedly over the course of a year. Professionals must monitor the progress of children with cochlear implants regularly, especially within the first year of implantation, and criterion-referenced measures provide a more effective solution than norm-referenced measures.

Many different types of criterion-referenced assessment instruments are available to professionals, including checklists, developmental scales, and progress-monitoring instruments. Checklists and developmental scales can be based on teacher report, parent report, direct observation, and/or specific items designed to elicit responses directly from a child. Progress-monitoring instruments, such as the Dynamic Indicators of Basic Early Literacy Skills assessment (DIBELS), are designed specifically for monitoring the growth of a very specific skill at set intervals (Good, Kaminski, Smith, Laimon, & Dill, 2001). The rehabilitative team may consider information from all types of instruments to estimate the rate at which a child is improving.

Progress-monitoring instruments are designed to be easily administered, and they provide scores on a constant metric across many different test forms (Francis et al., 2008). Regular and easy administration allows a professional to take data across multiple time points without interfering with a child's typical intervention session or school day. Because the assessment instrument is administered many times, the scores a child receives should be consistent across time points. For example, if a child receives a score of 5 one week, 6 the next week, and 7 the following week, the intervals between scores of 5, 6, and 7 should indicate equal growth from the first to the second and the second to the third week.

In addition, a progress-monitoring instrument should be free from practice and form effects (Francis et al., 2008). A practice effect occurs if a child improves his or her score on an instrument because he or she is familiar with the measure, rather than because his or her skill has improved. A form effect occurs when test forms are not of equivalent difficulty. As a result, a change in a child's score may be the result of test-form difficulty, not skill improvement. For example, a test may require a child to read one paragraph one week and then a more difficult paragraph the next week. If the child has more errors in the second paragraph, he or she is subject to a form effect, not a skill regression.

All members of a rehabilitative team should be able to evaluate the appropriateness and validity of assessments used to measure the progress of speech, language, auditory, and academic skills. In the following sections, general criterion-referenced and progress-monitoring specific instruments that are frequently used to capture change in children's development are discussed.

SPECIFIC PROGRESS-MONITORING INSTRUMENTS

Assessments of Speech Production

Popular norm-referenced measures of articulation, such as the Arizona Articulation Proficiency Scale (AAPS-4) (Figure 9–1) and the Goldman-Fristoe Test of Articulation-3 (GFTA-2), were not



FIGURE 9–1. Shown here is an SLP administering the Arizona Articulation and Phonology Scale–4 to a 6-year-old implant recipient.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

designed to track progress over short periods of time (Fudala & Stengall, 20017; Goldman & Fristoe, 2015). Consequently, SLPs must use checklists or other progress-monitoring measures to track day-to-day change in vocal development and articulation skills (Table 9–2). Some of the criterion-referenced measures discussed in Chapter 4 are appropriate for this purpose. The Rosetti Infant–Toddler Language Scale (RI-TLS) tracks early speech-sound development as a part of the expressive language subscale (Rossetti, 1990). Other clinicians may choose to use articulation inventories, such as the Central Institute for the Deaf Phonetic Inventory, which tracks a child's production of speech sounds in all word positions (Moog, 1989). These inventories, however, do not always provide specific ages by which a sound should be mastered, but rather provide documen-

Table 9–2. Possible Measures for Progress Monitoring

Measure Name	*Type of Measure*	*Domains Assessed*	*Age/ Grade Range*	*Information Collected*
Rosetti Infant–Toddler Language Scales (RI-TLS)	Criterion referenced	Subtests: Interaction–attachment, pragmatics, gesture, play, language comprehension, language expression	0 to 36 months	Direct observation, behavior elicitation, parental report
Cottage Acquisition Scales for Listening, Language and Speech (CASSLS)	Criterion referenced	Forms available: preverbal, presentence, simple sentence, complex sentence, sounds and speech	0 to 8 years	Direct observation, behavior elicitation, parental report
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition	Criterion referenced	Audition, speech, cognition, social interaction, fine motor skills, gross motor skills	0 to 6 years	Direct observation, behavior elicitation, parental report
Central Institute for the Deaf Phonetic Inventory	Criterion referenced	Articulation	All ages	Observation
Phonetic–Phonologic Speech Evaluation Record	Criterion referenced	Articulation	All ages	Observation, behavior elicitation
Children's Speech Intelligibility Measure	Criterion referenced	Articulation	3 to 10 years	Behavior elicitation
MacArthur-Bates Communicative Development Inventory (CDI)	Criterion referenced	Forms: words and gestures, words and sentences	8 to 30 months	Direct observation, parental report
SKI-HI Language Development Scale	Criterion referenced	Receptive language, expressive language	0 to 5 years	Parental report
Index of Narrative Complexity	Criterion referenced	Narrative macrostructures and microstructures	School-age children	Behavior elicitation
Early Speech Perception Test (ESP)	Criterion referenced	Auditory discrimination and identification	3 to12 years	Behavior elicitation

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Table 9–2. *continued*

Measure Name	Type of Measure	Domains Assessed	Age/ Grade Range	Information Collected
Auditory Perception Test for the Hearing Impaired, Third Edition (APT/HI-3)	Criterion referenced	Auditory discrimination and identification	5+ years	Behavior elicitation
Phonological Awareness Literacy Screening Measures (PALS-PreK, PALS-K, PALS-1-3)	Criterion referenced	Name writing, alphabet knowledge, beginning sound awareness, rhyme awareness, nursery rhyme knowledge, print and word awareness, letter sounds, spelling, word recognition, passage reading, comprehension, fluency	Preschool to 3rd Grade	Behavior elicitation
Bracken School Readiness Assessment, Third Edition (BSRA)	Criterion referenced	Color knowledge, letter knowledge, numbers/ counting, comparison/ size knowledge, shape knowledge	3 to 6 years	Behavior elicitation
Dynamic Indicators of Basic Early Literacy Skills	Criterion referenced	Initial sound fluency, letter-naming fluency, phoneme segmentation fluency, nonsense-word fluency, oral reading fluency	Kindergarten to 6th grade	Behavior elicitation

tation showing improvement in articulation skills over time.

Some assessments specifically designed for measuring speech-production progress are available. The Children's Speech Intelligibility Measure, for example, provides many versions of a stimulus list (Wilcox & Morris, 1999). The SLP can score a child's productions across several week-long intervals to determine if regular progress is being made. This type of instrument, however, may not be appropriate for a child immediately following implantation; children develop articulation skills over the course of several years. Consequently, children may not produce age-appropriate phonemes for an extended time period following implantation. Other measures of vocal development may be used to track first-year progress.

Another widely used assessment tool, the Cottage Acquisition Scales for Listening, Language, and Speech, allows parents and therapists to compare listening, language, speech, and cognitive skill development to a timeline; a child's listening age is compared with his or her skill acquisition across those domains (Wilkes, 2001). The test forms for this measure are divided into preverbal, presentence, simple sentence, and complex-sentences levels, and one additional form is available to measure speech-sound production. SLPs, TODs, or EIs can use these forms to compare a child's skills in one domain (e.g., receptive language) with another (e.g., speech production). Other scales and checklists, including those from St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition, the Phonetic–Phonologic Speech Evaluation Record: A Manual, can also provide useful benchmarks for professionals to use to gauge children's progress (Tuohy, Brown, & Mercer-Moseley, 2005; Ling, 1991). If a child is not

STUDENTS-HUB.com Uploaded By: tuka abuzneid

developing speech-production skills at the rate anticipated by the cochlear implant team, the group may discuss altering a child's cochlear implant settings or changing intervention techniques.

Assessments of Language

As with speech production, many common language tests, such as the Preschool Language Scale–5, Peabody Picture Vocabulary Test (PPVT–5), or the Clinical Evaluation of Language Fundamentals-Fifth Edition, are not designed or appropriate for capturing change in specific language skills across short periods of time (Dunn, 2019; Wiig, Semel & Secord, 2013; Zimmerman, Steiner, & Pond, 2010). A rehabilitation team may instead turn to criterion-referenced measures designed to capture change in a child's ability to produce language structures (e.g., acquisition of the past-tense grammatical morpheme "ed"). A child's needs identified during baseline testing should determine which measures are appropriate for tracking the progress of language skills.

Language-skill progress-monitoring instruments have been recently developed for children who have sufficient language to complete a language sample. For example, the Index of Narrative Complexity provides a scale for rating the quality of narrative productions over time (Petersen, Gillam, & Gillam, 2008); however, these types of measures are not necessarily appropriate for a recently implanted child, and they should only be used with older children who have either had an implant for many years or have acquired an implant due to a progressive loss.

Criterion-based measures and checklists of language skills designed for children with cochlear implants are available. The aforementioned criterion-referenced measures, such as the RI-TLS, the CASLLS, St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition, SKI-HI Developmental Language Scale, and the MacArthur-Bates Communicative Development Inventories (see Chapter 4), can all be used to track early language development in children (Fenson et al., 2006; Rossetti, 1990; Tuohy et al., 2005; Watkins, 2004; Wilkes, 2001). These scales can capture changes in language performance during the first year of implant use.

Assessments of Auditory Skills

Auditory skills are among the skills most likely to improve quickly postimplantation (Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004). A child's early auditory skills may change his or her development across other domains; therefore, capturing change in skills directly related to auditory function is one of the most important tasks for a child's rehabilitative team. The Early Speech Perception Test (ESP) and the Auditory Perception Test for the Hearing Impaired (APT/HI-3), described in Chapter 4, can be used for the purposes of progress monitoring (Allen, 2015; Moog & Geers, 1990); however, neither test can be administered very quickly. Consequently, other measures of auditory development may be more useful for frequent tracking of changes in auditory development.

Many curricula and checklists allow professionals to track a child's auditory development. St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition, as well as the Cottage Acquisition Scales for Listening, Language, and Speech provide scales specific to auditory development (Tuohy et al., 2005; Wilkes, 2001). The Functional Auditory Performance Indicators Scale (FAPI) also assesses auditory development across the following categories: sound awareness, meaningful sound, auditory feedback, localization, auditory discrimination, short-term memory, and linguistic auditory processing (Stredler-Brown & Johnson, 2004). Professionals, in collaboration with parents, can use these various scales to generate a profile describing a child's listening skills and progress over short periods of time. If a child is not acquiring early auditory skills, the team may choose to adjust his or her implant settings to ensure maximal benefit from the device.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Assessments of Academic Knowledge

A variety of instruments are available for tracking progress in academic skill sets, including phonological awareness, reading, writing, and mathematical skill development. TODs, and in some cases, SLPs, can regularly administer these instruments to describe a child's academic progress postimplantation.

Many classroom curriculums provide assessment tools to track a child's knowledge of recently taught concepts. Other published tools track progress across broader sets of skills. The Dynamic Indicators of Basic Early Literacy Skills (DIBELS), for example, measures growth in skills related to reading (Good et al., 2001). Other tools, including the Phonological Awareness Literacy Screening (PALS) or the Bracken School Readiness Assessment (third edition), can also be used periodically to measure a child's skill mastery (Bracken, 2007; Invernizzi, Meier, Swank, & Juel, 2004). TODs can collaborate with general education teachers to determine whether a child's rate of academic skill progress is appropriate for his or her listening experience. In addition, the TOD can observe the ways in which a child's speech and language skills impact his or her academic achievement. If a child's academic progress is inconsistent with his or her progress across other domains, the team may choose to provide additional educational support to a child in his or her school setting.

THERAPY POSTIMPLANTATION

After a child receives a cochlear implant and gains access to sound, possibly for the first time, parents often need guidance not only to use the implant equipment, but also to learn to use the most appropriate and efficient language-facilitation techniques. SLPs, TODs, and EIs all can play a role in helping a parent or teacher develop the tools needed to promote language development. To work effectively as a team, all team members must (a) understand a child's current level of functioning, (b) recognize the next stage of development (goal of intervention), (c) know the best techniques for encouraging development, and (d) agree what behaviors will provide the evidence that a goal is met. Establishing these guidelines within team meetings ensures that families and professionals are able to work together toward a common goal.

The parent's role is central to developing and achieving intervention goals. All families must fit intervention for their child into their daily routines; thus, professionals should be sensitive to the needs and capabilities of a family when planning treatment. It is not the professional's sole responsibility to determine goals and how they will be met; rather, professionals bring knowledge of typical and atypical development, as well as intervention techniques to the family, who can then make decisions about goals and treatment with guidance. One effective way of assessing a family's strengths and needs is to conduct a routines-based interview (McWilliam, Casey, & Sims, 2009). A routines-based interview requires interventionists to ask in-depth questions about a family's typical day to evaluate opportunities for communicative interventions.

SLPs, TODs, and EIs can help a family enhance their child's development by teaching a family about a child's expected trajectory of development. A clear understanding of the stages a child may progress through will help a rehabilitation team to develop treatment goals and methods.

The following sections review the possible stages of postoperative development and implications for intervention. This model assumes that a child has not previously had access to sound and is beginning the language-learning process with no knowledge of language. For children who may have a progressive or acquired loss, these principles can still be applied at appropriate stages (i.e., if a child already has sound detection, therapists can look to the next stage of development to set their goals and expectations).

Therapy Immediately Following Implantation

Many parents (and even professionals) are often disappointed to learn that most children are not prepared to listen, respond, and speak immediately following activation of a cochlear implant. In the same way that babies receive a year of language input before producing their first words, children with cochlear implants need time to develop their auditory skills prior to producing speech. Despite a lack of speech, children in the early stages of auditory development should make observable gains that professionals can monitor and encourage.

Throughout a child's first months postimplantation, the people who spend the most time

STUDENTS-HUB.com Uploaded By: tuka abuzneid

with a child throughout his or her day (e.g., parents, babysitters, teachers) play a vital role in helping a child develop these auditory skills. Early intervention, therefore, should focus on teaching caretakers to use effective strategies throughout the day. The role of the professional, in this case, is as a parent coach rather than teacher to the child.

According to Erber's four-level model of auditory development, the first step in auditory-skill acquisition is developing sound-detection skills (i.e., determining if a sound is present or absent) (Erber, 1982). Because many children are not used to attending to information coming from an auditory channel, children with cochlear implants have to learn to detect and attend to different types of environmental sounds. Basic detection abilities often develop quickly (Niparko, 2000). Within a day of initial implant activation, a child may begin to respond to sounds presented in the absence of other distractions; however, differentiated responses to different environmental sounds may develop more slowly over the first couple of months of sound access (Moore & Shannon, 2009). To encourage sound detection, the rehabilitation team will want to draw a child's attention to sounds of different types. These sounds can include staccato, novel sounds that occur in the environment (e.g., the telephone ringing, the doorbell ringing, the microwave beeping) and continuous, "white-noise" sounds (e.g., the dishwasher running). Sounds present in the environment of any child vary, so environmental sound-based activities are often unique to a specific family.

Following the development of auditory detection, children should begin to discriminate between different sounds, and to associate words with their referents (Erber, 1982). A child who is just learning to listen is not necessarily prepared to discriminate between individual phonemes of words (e.g., "map" versus "mat") (Niparko, 2000). Prior to developing those skills, children with cochlear implants first learn to discriminate between suprasegmental features of speech. Suprasegmental features include the pitch (high or low), loudness (loud or soft), and duration (long or short) of groups of speech sounds; thus, a child who is unable to distinguish between two words of similar duration with different phonemes (e.g., "cat" versus "dog") may be able to distinguish between words of varying gross duration ("ice cream cone" versus "cat"). Children vary in their recognition of suprasegmental differences between words: some children develop this ability early, whereas others take up to many months postimplant to discriminate between sounds (Snow & Ertmer, 2012). A rehabilitation team can emphasize the development of discrimination abilities while encouraging a child to connect sounds to objects. For example, the parent, SLP, TOD, and EI may choose to label objects in a child's environment with sounds that have different suprasegmental properties (e.g., teaching the child that the cat says "meeeooww" and the dog says "woof woof"). Noting a child's ability to discriminate between and comprehend those labels provides a team with information about a child's auditory development. Acoustically highlighting features of speech may improve a child's early ability to learn and even use words (Simser & Estabrooks, 2001).

In addition to learning to discriminate word-level differences, within the first 8 months of listening children with cochlear implants may also learn to recognize rote phrases (Robbins, 2005). These phrases include those used frequently in everyday life, such as "shut the door," "sit down," "let's go!" etc. The rote phrases that an individual child hears likely vary across families. Parents and professionals can encourage the development of rote-phrase recognition by highlighting consistent phrases during a child's daily routines (Table 9–3). Furthermore, parents and professionals can track children's responses to these phrases when presented through audition alone (without visual cue). If a child is able to anticipate an action (e.g., looking to the door) following an auditory-only presentation of a rote phrase (e.g., "let's go!), he or she is showing signs of rote phrase comprehension.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

During the initial months following a child's implantation, parents should begin to use techniques for making certain sounds, words, and phrases acoustically salient to children (Simser & Estabrooks, 2001). These techniques, often labeled "acoustic highlighting," may contribute to children's ability to develop discrimination abilities. Parents can use many different acoustic-highlighting strategies within the context of their daily lives (see Table 9–3). For example, placing key words at the end of a phrase, slowing the rate of speech, or increasing the amplitude of a specific

Table 9–3. Acoustic Highlighting Strategies

Strategy	*Example*
Limit background noise.	Turn off the television, dishwasher, or noisy air-conditioner when interacting with the child
Speak near the cochlear implant microphone.	
Provide repetitions of key information.	Instead of giving a direction one time, provide multiple opportunities for a child to grasp the message. For example, "Look, the shoes are red! I see red shoes! They're red!"
Limit the length of spoken instruction.	Instead of giving two to three instructions at one time, divide the key points into several parts. For example, "Go get your coat . . . and go to the door."
Slow the rate of speech.	
Place key words at the end of an utterance.	Give key semantic information at the end of the sentence (i.e., "Go to the door.")

word improves the acoustic salience of that word to a child with hearing loss. The rehabilitation team can work together to ensure that a child's attention is drawn to acoustically salient sounds, words, and phrases during the first months of implant use.

Even before children with cochlear implants begin using words to communicate, they can learn about the conventional use of spoken language (Goldin-Meadow & Mylander, 1984). Professional- and parent-led intervention activities can help children to understand that words are meaningful, that words can control the actions of others, and that people converse using sequences of speech sounds. Activities that encourage understanding of these communicative principles are often the same types of activities children participate in as infants, such as imitating nonsense sounds and syllables. Although these activities may not seem appropriate for children beyond infancy, parents and professionals should target these early-developing skills with newly implanted children who have little to no spoken language.

Therapy During the Early Stages of Language Learning

As children develop the ability to discriminate phonemes, they begin to understand and use words (Erber, 1982). Professionals can use published materials to track changes in a child's ability to discriminate between increasingly similar words. For example, the SPICE curriculum provides both auditory-training activities and progress-tracking scales designed to capture a child's ability to differentiate between minimally different words (Moog, Biedenstein, & Davidson, 1995). Though research does not currently prove or disprove that behavioral therapy can increase or decrease a child's discrimination abilities, professionals can track this development to set appropriate corresponding language goals.

Once a child is able to perceive and identify individual words, he or she can develop word-learning skills. To acquire new vocabulary, children with hearing loss benefit from frequent repetition (Simser & Estabrooks, 2001). Professionals may want to focus intervention on commonly used words and phrases during this phase of development to ensure that children are repeatedly hearing target vocabulary words throughout the day. This initial focus on frequently occurring, functional vocabulary words may provide children with the ability to interact with others during routines (e.g., mealtime or playtime).

As children learn and begin to combine words, they may develop knowledge of basic syntax and morphology. Children in the early stages of language learning often use sentence frames to

STUDENTS-HUB.com Uploaded By: tuka abuzneid

communicate. Sentence frames are frequently used phrases that can be combined with other words to communicate a message. For example, "where's the _____" and "look at _____" are sentence frames often used in child-directed speech (Cameron-Faulkner, Lieven, & Tomasello, 2003). Parents and professionals can encourage children with cochlear implants to use sentence frames and longer sentence structures by recasting and expanding sentences (DesJardin & Eisenberg, 2007). For example, a child might say, "Look at dog," and a parent could recast and expand the utterance by replying, "Yes! Look at that big dog in the park!" During this phase of development, children also begin to use grammatical morphemes. Many morphemes in the English language are marked by high frequency, unstressed phonemes (e.g., plural "s" and regular past tense "-ed"). These particular morphemes can be particularly difficult for children with hearing loss to perceive and, consequently, produce (Spencer, Tye-Murray, & Tomblin, 1998). SLPs and TODs can help parents to recognize these morphemes in connected speech and highlight or emphasize them for their child with a cochlear implant. Both parents and professionals should continue to use acoustic highlighting techniques (see Table 9–3) during this stage of development to ensure that a child has access to important linguistic information.

Preschool children with cochlear implants, in addition to developing basic linguistic knowledge, can begin to acquire early literacy skills. For example, children may begin to develop early print knowledge and phonological awareness. Print knowledge may include concepts of print (e.g., reading books from left to right) and word knowledge (e.g., words are comprised of letters and letters represent sounds). Phonological awareness refers to the ability to recognize and analyze the sounds of words separate from their meaning. Children can acquire both print knowledge and phonological awareness through shared storybook reading (Desjardin, Ambrose, & Eisenberg, 2009). SLPs and TODs may focus intervention on mothers' use of facilitative techniques. Throughout the early stages of language and literacy development, parents and professionals can work as partners to ensure that language-learning opportunities are maximized throughout a child's day.

Therapy During Later Stages of Language Learning

Children with cochlear implants may develop language skills rapidly in the first 2 to 3 years postimplantation (Nicholas & Geers, 2007). Despite growth during this period, however, it is likely that a child's language skills will continue to lag behind those of peers with normal hearing; thus, professionals play a role in continuing to help a child with cochlear implant to acquire the necessary speech and language skills to function academically and socially.

Children with cochlear implants vary greatly in their auditory working memory skills and in their ability to listen in unaccommodating environments (Dowell, Dettman, Blamey, Barker, & Clark, 2002). Professionals can work to increase a child's confidence listening to sentences of increasing length and in noisy environments, and to make accommodations in the child's classroom and home environment to provide optimal listening experiences. Both parents and professionals can engage a child in activities that require him or her to follow directions of increasing complexity (e.g., "Get the red crayon and put it in the box on the shelf"). The experience of listening to complicated directions may build a child's confidence in his or her ability to retain and comprehend this type of information in real-world settings (Cole & Flexer, 2007). Similarly, parents and professionals can give a child experience listening through noisy environments. In addition, SLPs and TODs can work with general educators and parents to examine the listening demands placed on a child in his or her natural environment. When a child is asked to learn and retain new academic information, ideally he or she should have the opportunity to learn without interference from noise (Schafer & Thibodeau, 2006). Reduction of background noise can improve a child's learning experience.

SLPs may also want to devote some individual therapy time to correcting a child's lingering speech-production errors. After a child is able to perceive and discriminate individual speech phonemes, he or she can begin to correct them in conversational speech; however, some children with cochlear implants need intervention to overcome poor speech-production habits (Tobey, Geers, Sun-

STUDENTS-HUB.com Uploaded By: tuka abuzneid

darrajan, & Shin, 2011). Parents and professionals can help a child to monitor his or her own speech production throughout the day to identify and correct errors.

Even after a child with a cochlear implant has mastered basic grammar skills, he or she may still have subtle language deficits. Children with hearing loss, including children with cochlear implants, have less robust lexical knowledge than children with normal hearing. Vocabulary deficits can impact a child's ability to complete academic work. For example, a child with hearing loss may struggle with a social studies assignment if he or she does not understand most of the vocabulary used. Preteaching vocabulary and language structures that are unfamiliar to a child can improve his or her ability to function in a general education classroom setting (Stith & Drasgow, 2005). Children with hearing loss may also struggle to understand nonliteral language (e.g., idioms, sarcasm) (Schorr, Roth, & Fox, 2008). SLPs, TODs, and parents can all work to explicitly teach a child about nonliteral uses of language. A child's individual language deficits should drive the goals of his or her therapy.

As children with cochlear implants enter elementary school, rehabilitative teams should monitor the acquisition of literacy-related skills. Children with hearing loss, including children with cochlear implants, generally have poor reading outcomes related to both decoding and comprehension (Geers & Hayes, 2011). Children with skill deficits related to either decoding or comprehension may need supplemental instruction in those areas. SLPs in particular can apply their specialized knowledge of phonological awareness to a rehabilitative team's intervention plan (Spencer, Schuele, Guillot, & Lee, 2008).

STUDENTS-HUB.com

Adult Intervention

In addition to serving children with cochlear implants, SLPs and TODs can play a role in the rehabilitation of adults who receive cochlear implants. By the time an adult receives an implant, it is likely that he or she has already had the linguistic and academic training necessary for him or her to function in the world. A cochlear implant, however, provides an adult with new levels of access to sound. As a result, adults with cochlear implants may be able to develop better auditory-functioning skills or speech skills post-implant (Fu, Galvin, Wang, & Nogaki, 2005).

A professional can guide an adult with a cochlear implant through structured exercises to improve his or her listening skills over the course of the first year post-implantation (Caposecco, Hickson, & Pedley, 2011). Adults, like children, can move through several stages of auditory functioning. First, an adult may begin with simple detection exercises (e.g., is the sound there or not?), move into discrimination exercises (e.g., differentiate sounds and words of varying length, pitch, loudness, and phonemes), and then to comprehension of longer phrases. The amount of gain an adult can make may be limited depending on his or her pre-implant language skills and duration of deafness (Caposecco et al., 2011). SLPs or TODs may provide structured guidance to an adult to help him or her reach maximum listening potential.

Improved access to sound also may provide some adults with an opportunity to change articulation habits. Instructing adults in new articulation patterns can be similar to working with a school-age child. An SLP can talk directly to the adult about the correct physiologic way to produce a phoneme and provide opportunities for production across words, phrases, and sentences in initial, medial, and final positions. The amount of change an adult is able to make is likely dependent on his or her speech-perception ability and willingness to change habits.

Uploaded By: tuka abuzneid

CONCLUSION

Rehabilitative teams, which may include parents, audiologists, TODs, SLPs, EIs, and many other professionals, must work together to evaluate a child's postoperative outcomes. Progress monitoring informs decisions about intervention. To communicate about progress and intervention, all members of a rehabilitative team should meet regularly. If the progress-monitoring and intervention

expectations of various team members are clear from the beginning of treatment, all parties can contribute to a child's progress. Using the various progress-monitoring tools available, rehabilitative teams can track a child's growth to maximize his or her spoken-language outcomes.

REFERENCES

Allen, S. G. (2015). *Auditory Perception Test for the Hearing Impaired* (3rd ed.). San Diego, CA: Plural Publishing.

Bracken, B. A. (2007). *Bracken School Readiness Assessment* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Cameron-Faulkner, T., Lieven, E., & Tomasello, M. (2003). A construction-based analysis of child directed speech. *Cognitive Science, 27,* 843–873.

Caposecco, A., Hickson, L., & Pedley, K. (2011). Cochlear implant outcomes in adults and adolescents with early-onset hearing loss. *Ear and Hearing, 33*, 209–220.

Cole, E. B., & Flexer, C. A. (2007). Children with hearing loss: Developing listening and talking birth to six. San Diego, CA: Plural Publishing.

Desjardin, J., Ambrose, S., & Eisenberg, L. (2009). Literacy skills in children with cochlear implants: The importance of early oral language and joint storybook reading. *Journal of Deaf Studies and Deaf Education, 14*(1), 22–43.

DesJardin, J. L., & Eisenberg, L. S. (2007). Maternal contributions: Supporting language development in young children with cochlear implants. *Ear and Hearing, 28l,* 456–469.

Dowell, R. C., Dettman, S. J., Blamey, P. J., Barker, E. J., & Clark, G. M. (2002). Speech perception in children using cochlear implants: Prediction of long-term outcomes. *Cochlear Implants International, 3,* 1–18.

Dunn, D. M. (2019). *Peabody Picture Vocabulary Test* (5th ed.). Bloomington, MN: NCS Pearson.

Erber, N. (1982). Auditory training. Washington, DC: Alexander Graham Bell Association for the Deaf.

Fenson, L., Marchman, V., Thal, D., Dale, P., Reznick, S., & Bates, E. (2006). *The MacArthur Communicative Development Inventories: User's guide and technical manual* (2nd ed.). Baltimore, MD: Brookes Publishing.

Francis, D. J., Sanit, K. L., Barr, C., Fletcher, J. M., Varisco, A., & Foorman, B. R. (2008). Form effects on the estimation of students' oral reading fluency using DIBELS. *Journal of School Psychology, 46,* 315–342.

Fu, Q. J., Galvin, J., Wang, X., & Nogaki, G. (2005). Moderate auditory training can improve speech production of adult cochlear implant patients. *Acoustics Research Letters Online, 3,* 106–111.

Fudala, J. B., & Stengall, S. (2017). *Arizona Articulation Proficiency Scale (AAPS-4)* (4th revision). Torrance, CA: Western Psychological Services.

Geers, A. E., & Hayes, H. (2011). Reading, writing, and phonological processing skills of adolescents with 10 or more years of cochlear implant experience. *Ear and Hearing, 32,* 49–59.

Goldin-Meadow, S., & Mylander, C. (1984). Gestural communication in deaf children: The effects and noneffects of parental input on early language development. *Monographs of the Society for Research in Child Development, 49,* 1–151.

Goldman, R., & Fristoe, M. (2015). *Goldman Fristoe Test of Articulation (GFTA-3)* (3rd ed.). Minneapolis, MN: Pearson Inc.

Good, R. H., Kaminski, R. A., Smith, S., Laimon, D., & Dill, S. (2001). Dynamic Indicators of Basic Early Literacy Skills (DIBELS) (5th ed.). Eugene, OR: University of Oregon.

Invernizzi, M., Meier, J. D., Swank, L., & Juel, C. (2004). *PALS: Phonological Awareness Literacy Screening*. Charlottesville, VA: University of Virginia Press.

Ling, D. (1991). *Phonetic–phonologic speech evaluation record: A manual*. Washington, DC: Alexander Graham Bell Association for the Deaf.

McWilliam, R. A., Casey, A. M., & Sims, J. (2009). The routines-based interview: A method for gathering information and assessing needs. *Infant & Young Children, 22,* 224–233.

Moog, J. S. (1989). *Central Institute for the Deaf Phonetic Inventory.* St. Louis, MO: Central Institute for the Deaf.

Moog, J., Biedenstein, J., & Davidson, L. (1995). *SPICE: The Speech Perception Instructional Curriculum and Evaluation.* St. Louis, MO: Central Institute for the Deaf.

Moog, J. S., & Geers, A. (1990). *Early Speech Perception Test for Profoundly Hearing-Impaired Children.* St. Louis, MO: Central Institute for the Deaf.

Moore, D. R., & Shannon, R. V. (2009). Beyond cochlear implants: Awakening the deafened brain. *Nature Neuroscience, 12,* 686–691.

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with profound hearing loss. *Journal of Speech, Language and Hearing Research, 50,* 1048–1062.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Niparko, J. (2000). *Cochlear implants principles and practices* (2nd ed.). Baltimore, MD: Lippincott, Williams, and Wilkins.

Petersen, D. B., Gillam, S. L., & Gillam, R. B. (2008). Emerging procedures in narrative assessment: The Index of Narrative Complexity. *Topics in Language Disorders, 28,* 115–130.

Robbins, A. M. (2005). *Clinical red flags for slow progress in children with cochlear implants. Loud and clear.* Valencia, CA: Advanced Bionics.

Robbins, A. M., Koch, D. B., Osberger, M. J., Zimmerman-Phillips, S., & Kishon-Rabin, L. (2004). Effect of age at cochlear implantation on auditory skill development in infants and toddlers. *Archives of Otolaryngology-Head & Neck Surgery, 130,* 570–574.

Rossetti, L. (1990). *Rosetti Infant–Toddler Language Scale (RI-TLS).* East Moline, IL: LinguiSystems.

Schafer, E. C., & Thibodeau, L. M. (2006). Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements. *American Journal of Audiology, 15,* 114–126.

Schorr, E. A., Roth, F. P., & Fox N. A. A. (2008). Comparison of the speech and language skills of children with cochlear implants and children with normal hearing. *Communicable Disease Quarterly, 29,* 195–210.

Simser, J., & Estabrooks, W. (2001). What is the hand cue? What is acoustic highlighting? In W. Estabrooks (Ed.), *50 frequently asked questions about auditory verbal therapy*. Toronto, Canada: Learning to Listen Foundation.

Snow, D. P., & Ertmer, D. J. (2012). Children's development of intonation during the first year of cochlear implant experience. *Clinical Linguistics and Phonetics, 26,* 51–70.

Spencer, E. J., Schuele, C. M., Guillot, K. M., & Lee, M. W. (2008). Phonemic awareness skill of speech–language pathologists and other educators. *Language, Speech, and Hearing Services in Schools, 39,* 512–520.

Spencer, L., Tye-Murray, N., & Tomblin, J. B. (1998). The production of English inflectional morphology, speech production and listening performance in children with cochlear implants. *Ear and Hearing, 19,* 310–318.

Stith, J., & Drasgow, E. (2005). Including children with cochlear implants in regular education classrooms. *Teaching Exceptional Children Plus, 2,* 1–9.

Stredler-Brown, A., & Johnson, C. D. (2004). Functional Auditory Performance Indicators (FAPI): An integrated approach to auditory skill development Denver, CO: Colorado Department of Special Education.

Tobey, E. A., Geers, A. E., Sundarrajan, M., & Shin, S. (2011). Factors influencing speech production in elementary and school-aged cochlear implant users. *Ear and Hearing, 32,* 27–38.

Tuohy, J., Brown, J., & Mercer-Moseley, C. (2005). *St. Gabriel's curriculum for the development of audition, language, speech, cognition, early communication, social interaction, fine motor skills, and gross motor skills* (2nd ed.). Sydney, Australia: St. Gabriel's Auditory-Verbal Early Intervention Centre.

Watkins, S. (2004). *SKI-HI Language Development Scale,* 2nd Edition. North Logan, UT: HOPE, Inc.

Wiig, E. H., Semel, E., & Secord, W. A. (2013). *Clinical Evaluation of Language Fundamentals (CELF-5)* (fifth edition). Bloomington, MN: Pearson, Inc.

Wilcox, K., & Morris, S. (1999). *Children's Speech Intelligibility Measure.* London, UK: The Psychological Corporation.

Wilkes, E. M. (2001). *Cottage Acquisition Scales for Listening, Language, and Speech* (2nd ed.). San Antonio, TX: Sunshine Cottage School for Deaf Children.

Zimmerman, I. L., Steiner, B. S., & Pond, R. E. (2010). *Preschool Language Scale (PLS-5)* (5th ed.). San Antonio, TX: The Psychological Corporation.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid

10

Assessing Pre- and Postoperative Outcomes for Adults and Children: What Does the Future Hold and What Might We Be Missing?

René H. Gifford

INTRODUCTION

The primary purpose of this text is to provide a handbook for clinicians who will be assessing pre- and postimplant performance and overall outcomes for cochlear implant recipients. The focus has been on evidence-based, best practices and considerations for patient management in our current clinical environment. A recurring theme has been that cochlear implants and patient management have both evolved rapidly since the FDA approved multichannel implants for adults and children in 1985 and 1990, respectively. Given this evolution, it would follow that an expected element of our future is that clinical practices and patient management will most certainly change. It is also likely that we may be missing critical elements that are relevant to a patient's candidacy and postoperative assessment—even today. This chapter discusses the components of cochlear implant candidacy and postoperative assessment that we may be overlooking such as risk for cognitive decline, listening effort, auditory-related fatigue, and multisensory assessment. Just as with assessing candidacy for cochlear implantation, these metrics may ultimately also prove useful for determining candidacy for a second cochlear implant—a clinical decision that is not currently data driven.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

RISK FOR COGNITIVE DECLINE

Dementia and Link with Hearing Loss

According to the World Health Organization (WHO), by 2020, the number of persons over 60 years of age will outnumber children under 5 years of age (WHO, 2018). In 2018, there were 125 million individuals ≥80 years around the world; however, by 2050, this number will increase to nearly 450 million worldwide (WHO, 2018). The projected gains in life expectancy are even greater for individuals living to older ages. The global population of individuals ≥85 years is expected to increase by over 350% from 2010 to 2050 (Mahishale, 2015). We are not just experiencing a global increase in life expectancy, we are observing an overall aging of the world's population. Figure 10–1 shows the shift in the percentage of older versus younger persons from 1950 and projected to 2050 across a number of geographical locations (United Nations, 2017). As shown in Figure 10–1, in North America and Europe, we have already experienced a significant shift in population statistics such that we now have more individuals over 60 years than children 14 years and under. Such a rapid shift in the world's aged population brings with it a number of societal, economic and health-related issues.

One of the health-related consequences of an aging population is a greater incidence of dementia. The incidence of dementia increases dramatically with age every decade over age 60. Multiple reports have estimated that the overall prevalence of dementia is expected to double over the next twenty years reaching a global prevalence of 1 in 85 individuals *of all ages*, by the year 2050 (Ferri et al., 2005; Prince & Jackson, 2009). Alzheimer's Disease International (Prince & Jackson, 2009) has reported that in North America, over 30% of individuals aged 85 and older and nearly 40% of those over 90 years have dementia. Hebert and colleagues projected that over 50% of individuals over 85 years will have dementia by 2050 (Hebert, Weuve, Scherr, & Evans, 2013). Thus it is a reality that clinicians working with the adult population will be encountering individuals exhibiting signs of cognitive decline.

In 2016, Goman and Lin reported that there were approximately 38.1 million Americans ≥20 years with documented hearing loss (Goman & Lin, 2016). Out of the 38.1 million Americans with hearing loss, 36.0 million (94.4%) have mild-to-moderate hearing loss and 2.1 million (5.5%) have severe-to-profound hearing loss. There are a number of recent reports demonstrating a link between age-related hearing loss (presbycusis) and dementia. Presbycusis has been shown to be related to poorer cognitive functioning (Dawes et al., 2015; Gurgel et al., 2014; Heywood et al., 2017; Kuiper et al., 2015; F. R. Lin, Niparko, & Ferrucci, 2011; Livingston et al., 2017; Tay et al., 2006) and incident dementia (Davies, Cadar, Herbert, Orrell, & Steptoe, 2017; Deal et al., 2017, 2018; Fritze et al., 2016; Golub et al., 2017; F. R. Lin, Metter, et al., 2011) as compared to age-matched individuals with normal or near-normal hearing. Lin (2012) reported that older adults with even mild hearing loss have a 2-fold risk of incident dementia and older individuals with severe-to-profound hearing loss have a 5-fold increased risk of developing dementia (F. R. Lin, 2012). This is the population of individuals that will most generally be seen in the cochlear implant clinic.

The underlying mechanisms for the association between presbycusis and dementia are not fully understood. Lin (2012) explained that there are many possible mechanisms including the effects of hearing loss on cognitive processing (Peele, Troiani, Grossman, & Wingfield, 2011; Peele, Troiani, Wingfield, & Grossman, 2010), increased cognitive load (Cardin, 2016; Van Engen & McLaughlin, 2018; Wingfield, Tun, & McCoy, 2005), as well as social isolation (Ray, Popli, & Fell, 2018). Might it be the case that mitigating the communicative and social isolation effects of severe hearing loss with cochlear implantation may also decrease the risk of developing dementia? Current research does not allow for us to definitively answer this question at this point in time. Future research on this topic, if confirmatory, could translate to further expansion in criteria for adult cochlear implantation.

Primary care physicians are acutely aware of the need for early identification of cognitive decline in order to implement an effective treatment plan

STUDENTS-HUB.com Uploaded By: tuka abuzneid

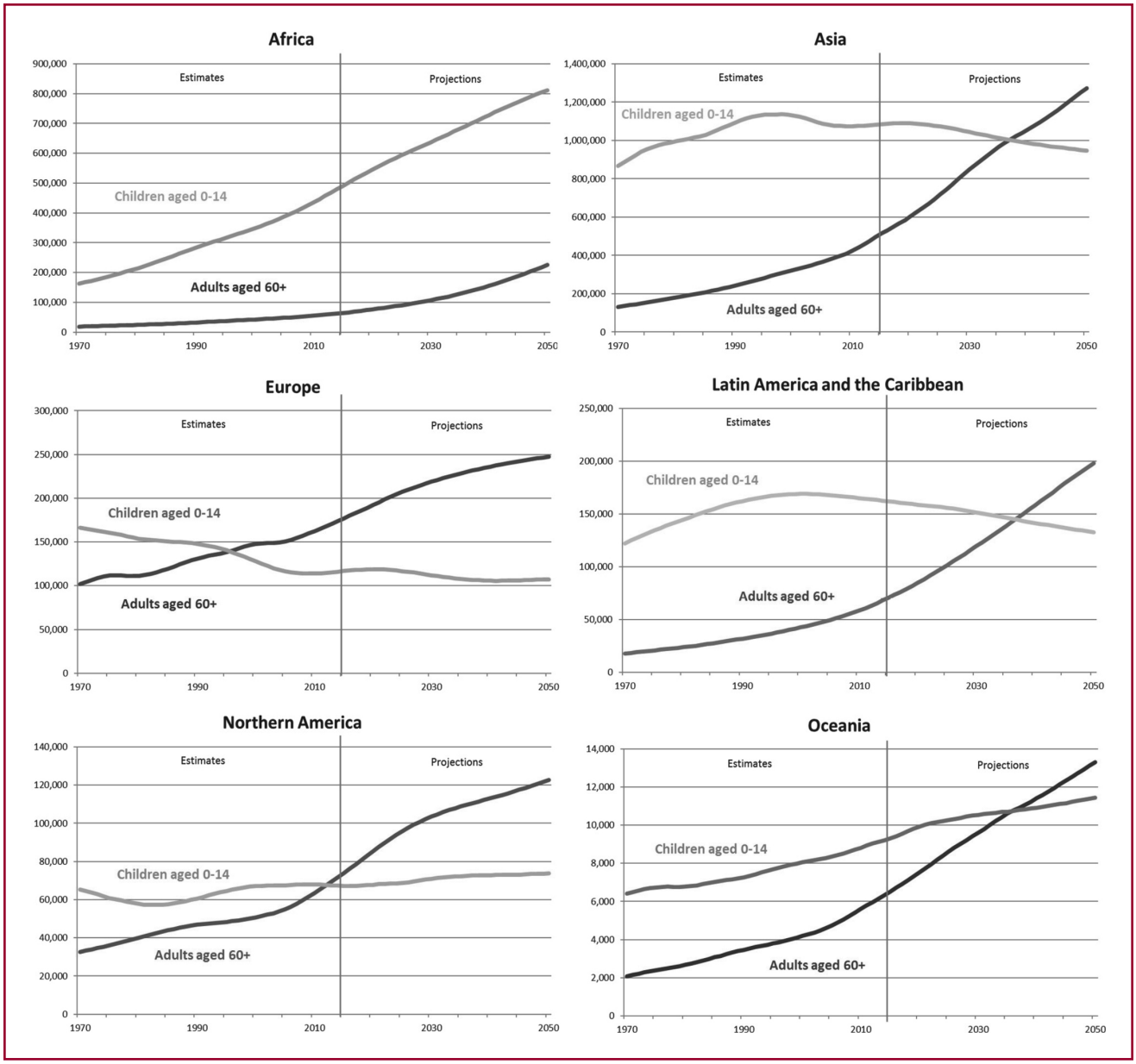


FIGURE 10–1. Population (in millions) as a function of date across for various geographical locations. From *World Population Prospects 2017 – Data Booklet (ST/ESA/SER.A/401)*, by United Nations, Department of Economic and Social Affairs, Population Division, © 2017 United Nations. Reprinted with the permission of the United Nations.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

(Galvin & Sadowsky, 2012; Moran et al., 2012; Simmons, Hartmann, & Dejoseph, 2011). For older individuals with significant hearing loss *and* cognitive decline, it may be the case that early and aggressive audiologic/otologic management may ultimately play a substantial role in the overall treatment for the individual. Indeed research has shown that individuals 65 years or older with bilateral severe-to-profound sensorineural hearing loss exhibited significantly improved scores on various assessments of neurocognitive function following cochlear implantation (Ambert-Dahan et al., 2017; Claes, Van de Heyning, Giles, Van Rompaey, & Mertens, 2018; Cosetti et al., 2016;

Jayakody et al., 2017; Mosnier, Bebear et al., 2015; Mosnier, Vanier et al. 2018; Sonnet et al., 2017). However, it is also possible that hearing loss may have contributed to poor preoperative scores, particularly for those assessments requiring auditory-based instruction. Nonetheless, there is growing evidence that the use of appropriate hearing technology—whether it be cochlear implants for individuals with more severe hearing losses or hearing aids for milder hearing losses—may prove beneficial for mitigating cognitive decline and even improving various aspects of neurocognitive function.

The next decade will likely bring much greater evidence about the relationship between hearing loss and dementia, as well as the effectiveness of various hearing interventions for slowing or possibly stopping cognitive decline. As such, clinical audiologists may play an important role in the *screening* for cognitive decline in our adult patient population (Beck, Weinstein, & Harvey, 2018). Such a widespread screening may also provide the Cochlear Implant team with important information about which patients should be referred for neuropsychology or neurology consult—a referral that might not be made unless an individual is seen regularly by his/her primary care physician and exhibits signs of cognitive decline during examination.

Screening for Cognitive Decline

There are a number of available screening instruments for cognitive impairment. One of the most widely used tools is the mini-mental state examination (MMSE) (Folstein, Folstein, & McHugh, 1975). The MMSE is a validated screening tool of cognitive function and administration takes approximately 5 to 10 minutes. The MMSE includes tests of orientation, attention, memory, language and visual-spatial skills. Table 10–1 provides an example question from the MMSE for each of the subscales. Points are scored for every portion of a question answered correctly, with a maximum of 30 possible points. Generally, a score of 25 to 30 represents normal cognition, with scores 24 and lower representing some degree of cognitive decline.

Another commonly used screener of cognitive decline is the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). The MoCA is a validated cognitive screener probing various aspects of neurocognitive function including, but not limited to, attention, concentration, memory, executive function, language, visual-spatial skills, and orientation. The MoCA takes approximately 10 minutes to administer and has a total possible score of 30. Individuals scoring 25 or lower are at risk for cognitive decline. The MoCA has been validated across over 50 languages (e.g., Arabic, Cantonese, English, French, German, Hebrew, Italian, Japanese, Mandarin, Russian, etc.) and has even successfully administered over the phone (Wong et al., 2015) and is now available in the App store for tablet-based administration. Of course, in order to administer a screening tool effectively over the phone or even via tablet, the individual being screened should have normal or near-normal

Table 10–1. Example Questions Gauging Each of the Five Subscales for the MMSE

STUDENTS-HUB.com Uploaded By: tuka abuzneid

MMSE Subscale	*Example question*
Orientation	What is today's date?
Attention	Count backwards from 100 by sevens.
Memory	Recall items identified earlier in the assessment.
Language	Construct a sentence about anything.
Visual-spatial skills	Patient is shown a picture of two intersecting polygons and is asked to copy the picture.

hearing acuity given auditory-based instructions. Concerns about hearing loss potentially impacting the results of cognitive screening tools motivated the development of the Hearing Impaired MoCA (HI-MoCA) (V. Y. Lin et al., 2017). The HI-MoCA is presented visually via timed computer administration without the need for auditory-based instruction.

There have been recent reports of cochlear implant programs including some type of cognitive assessment in the candidacy evaluation (Holder, Reynolds, Sunderhaus, & Gifford, 2018; Moberly, Castellanos, & Mattingly, 2018; Mosnier, Bebear et al., 2015; Mosnier, Vanier et al. 2018; Rossi-Katz & Arehart, 2011); however, it is unknown how prevalent preoperative cognitive screening or assessment is in cochlear implant programs and whether the preoperative cognitive data would be clinically meaningful for predicting postoperative outcomes. A report by Heydebrand and colleagues (2007), however, found no correlation between preoperative measures of general cognitive function and postoperative speech understanding outcomes for 37 adult implant recipients ranging in age from 23 to 80 years. The obvious limitations of the study were a small sample size and a broad range of participants' ages with many participants not likely to be at risk for cognitive impairment. Moberly and colleagues investigated the relationship between preoperative neurocognitive function and postoperative speech recognition outcomes in a group of 31 adult cochlear implant candidates (Moberly et al., 2018). They found a significant correlation between preoperative measures of working memory and nonverbal reasoning and postoperative sentence recognition in noise. Given the results from these studies, a larger-scale assessment of the relationship between preoperative measures of cognitive function and postoperative outcomes is certainly warranted, as this could serve as an important variable for predicting postoperative outcomes.

Using other measures of neurocognitive function including general intelligence, working memory, verbal learning, processing speed, and memory, there have been reports of a correlation with postoperative speech understanding for both adults (Heydebrand, Hale, Potts, Gotter, & Skinner, 2007; Lyxell et al., 1996; Mattingly, Castellanos, & Moberly, 2018; G. N. L. Smith, Pisoni, & Kronenberger, 2018) and children (AuBuchon, Pisoni, & Kronenberger, 2015; Kronenberger, Colson, Henning, & Pisoni, 2014; Kronenberger, Henning, Ditmars, Roman, & Pisoni, 2018; Pisoni, 2000; G. N. L. Smith et al., 2018; Steven et al., 2011). Most cochlear implant programs are not routinely assessing neurocognitive function for pediatric implant candidates with the exception of older children who may exhibit signs of global developmental delay. However, postoperative assessment of neurocognitive function may prove clinically valuable for guiding intervention, training, and recommendations for assistive hearing technologies.

LISTENING EFFORT AND FATIGUE

Hearing loss is known to increase the effort expended for cognitive and linguistic processes (Hétu, Riverin, Lalande, Getty, & St-Cyr, 1988; Meister, Schreitmuller, Ortmann, Rahlmann, & Walger, 2016; Nachtegaal, Smit, et al., 2009; Peele et al., 2010; Pichora-Fuller, 2007; Rönnberg, Rudner, Foo, & Lunner, 2008; Shinn-Cunningham & Best, 2008; Zekveld, George, Kramer, Goverts, & Houtgast, 2007). This has also been referred to as *listening effort*—which specifically refers to the resources expended for attention and cognition that are required for speech understanding (Downs, 1982; Feuerstein, 1992; Fraser, Gagné, Alepins, & Dubois, 2010; Gosselin & Gagné, 2011; Hicks & Tharpe, 2002; Hornsby, 2013; Picou, Ricketts, & Hornsby, 2011). This is not unexpected as individuals with hearing loss—particularly those with demanding professional and/or social listening environments—report that by the end of the day, that they experience substantial fatigue. Indeed, a number of recent publications have demonstrated significantly greater auditory-related fatigue in children with hearing loss as compared to their peers with normal hearing (Gustafson, Key, Hornsby, & Bess, 2018; Hornsby et al., 2017; Hornsby, Werfel, Camarata, & Bess, 2014) as well as for adults with hearing loss

STUDENTS-HUB.com Uploaded By: tuka abuzneid

(Alhanbali, Dawes, Lloyd, & Munro, 2017, 2018; Hornsby & Kipp, 2016). An obvious question is should we be including estimates of expended listening effort and auditory-related fatigue in our test battery for cochlear implant candidate selection? Although an individual is able to achieve above criterion level performance on a sentence recognition metric does not mean that she or he did not experience significant difficulty with the task. Perhaps another way to phrase the question is, should individuals who happen to be better at top-down processing (i.e., filling in the gaps) be penalized by withholding cochlear implantation despite having significant communicative difficulty?

Physiologic Biomarkers of Stress and Listening Effort

There is currently no research available indicating how much cochlear implants may be able to impact one's degree of listening effort—though the anecdotal reports from clinical patients are noteworthy. Studies using measures of listening effort, such as pupillometry (Kramer, Kapetyn, Festen, & Kuik, 1997; Zekveld & Kramer, 2014; Zekveld, Kramer, & Festen, 2010, 2011; Winn & Moore, 2018), heart rate variability (Dorman et al., 2012; Mackersie & Kearney, 2017; Mackersie, MacPhee, & Heldt, 2015), or skin conductance (Mackersie & Cones, 2011; Mackersie & Kearney, 2017; Mackersie et al., 2015) may provide assistance in determining the degree of benefit afforded by cochlear implantation for individuals with significant hearing loss. Further, it is possible that measures of listening effort—objective or subjective—may also play a role in determining implant candidacy, particularly for patients who may be considered "borderline" candidates on the basis of audiometric testing.

STUDENTS-HUB.com

Objective Estimates of Listening Effort

Pupillometry

There are a number of objective or physiologic correlates of listening effort. Pupils dilate in response to cognitive workload with peak dilation occurring approximately 1 to 2 seconds after demand onset. Measuring degree and latency of pupil dilation has been used for a number of years to gauge cognitive processing load for tasks including mathematics and academic testing complexity (Ahern & Beatty, 1979; Klingner, Tversky, & Hanrahan, 2011) and memory recall (Granholm, Asarnow, Sarkin, & Dykes, 1996; Kahneman & Beatty, 1966; Klingner et al., 2011; Piquado, Isaacowitz, & Wingfield, 2010; Taylor, 1981). In recent years, pupil dilation responses have been used as a metric of listening effort for individuals with and without hearing loss. Audiology clinics that offer vestibular testing will likely already have video eye-tracking systems that can calculate pupil position for assessing oculomotor function. Pupillometry measures for gauging listening effort, however, will likely not be included in the clinical software as the triggering programs for syncing speech stimuli and the measurement of onset and peak dilation latency include specialized coding that is currently customized by individual research labs. Thus additional research is required to address its clinical applicability and efficacy for use in audiologic evaluation.

Heart Rate Variability

Heart rate variability (HRV) is a physiological correlate of stress. HRV measurements reflect beat-to-beat variation in the natural heart rate, created by the actions of the sympathetic and parasympathetic branches of the autonomic nervous system. When under stress, activity of the sympathetic nervous system activity is higher thereby decreasing heart rate variability. In less stressful conditions, there is greater activity of the parasympathetic nervous system, thereby increasing activity HRV.

Uploaded By: tuka abuzneid

A number of studies have showed significant decreases in HRV with increases in background noise levels as related to speech understanding for normal-hearing listeners (Dorman et al., 2012) and listeners with hearing loss (Mackersie & Kearney, 2017; Mackersie et al., 2015). Thus it is possible that measures of HRV could be used to estimate the degree of auditory-related stress for individuals with hearing loss—and also potentially for supplementing the implant candidacy test battery. Though more research is clearly needed, the potential for clinical relevance is high. HRV

measurement is rather simple and requires data from electrocardiogram (ECG) equipment already existing in most major medical centers—though its applicability and ease of use in the Audiology clinic is debatable without medically trained staff such as nurses or nursing assistants.

Skin Conductance

Skin conductance (also commonly referred to as galvanic skin response) is a measure reflecting the electrical conductance of the skin—which varies with moisture level. Skin moisture level is dependent upon activity of the sweat glands which are regulated by the sympathetic nervous system (primarily responsible for the body's fight or flight response). Thus skin conductance provides an indirect estimate of physiologic stress.

Mackersie and Cones (2011) evaluated the sensitivity of a number of physiologic markers of stress for gauging listening effort and task demand for individuals with normal hearing. Though they incorporated four physiologic measures of stress, including heart rate, skin conductance, skin temperature, and electromyography, mean changes in skin conductance was found to be most sensitive to increasing task demand. Mackersie and colleagues have also investigated use of skin conductance to assess reactivity to difficult listening tasks demonstrating greater reactivity to noise for listeners with hearing loss as compared to listeners with normal hearing (Mackersie et al., 2015).

Skin conductance is currently measured best from the palm of the hand or the sole of the foot, as these areas have particularly dense populations of eccrine glands. Eccrine glands are involved in thermoregulation and are particularly sensitive to emotional triggers and mental demand. Measurement of skin conductance is most generally achieved with electrodes placed on the palm of the hand, such as that employed during polygraph, or lie detector testing. Unlike ECG and oculomotor equipment, as discussed previously for the measurement of HRV and pupil dilation responses, skin conductance measuring and analysis equipment may not be widely available in a medical center environment. Thus, more research is necessary to address its clinical applicability and efficacy for use in audiologic evaluation.

Subjective Estimates of Listening Effort and Fatigue

Increased listening effort and auditory-related fatigue are known sequelae of hearing loss. Individuals with severe-to-profound hearing loss frequently report increased anxiety, stress, and mental fatigue in response to the communication demands in both their professional and social lives. These reports, however, are largely ignored in clinical practice despite the large social, emotional, and even financial impact.

Individuals with hearing loss have been shown to take significantly more sick leave due to stress-related complaints than individuals with normal hearing (Kramer, Kapteyn, & Houtgast, 2006; Nachtegaal, Festen, & Kramer, 2012). Individuals with hearing loss are also more likely to require longer recovery from work and work-related stress than individuals with normal hearing (Nachtegaal et al., 2012; Nachtegaal, Kuik, et al., 2009). Productivity at work is also negatively correlated with degree of hearing loss (Huddle et al., 2017; Nachtegaal et al., 2012). Thus it would make sense to assess degree of auditory-related fatigue among individuals presenting for cochlear implant candidacy evaluation. It is possible that cochlear implantation may actually increase one's work productivity—though additional research is necessary.

There are a number of questionnaires that were designed specifically to address subjective fatigue. These questionnaires, however, were not designed with auditory-related fatigue in mind. Rather the majority of questionnaires were designed to assess fatigue as related to chronic health conditions such as cancer, autoimmune disease, and sleep disorders. It is currently unclear what applicability such instruments would have for individuals with auditory-related fatigue. There are researchers currently working in this area and it is likely that the future will bring validated questionnaires designed to specifically assess fatigue as related to hearing and hearing loss.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Children and Listening Effort

A wealth of research suggests that a child's academic performance is greatly influenced by degree

of mental alertness. Sleep has generally been attributed as the primary underlying factor affecting a child's mental alertness in the classroom (A. Eliasson, A. Eliasson, King, Gould, & A. Eliasson, 2002; Gozal, 1998; Perez-Chada et al., 2007; Ravid, Afek, Suraiya, Shahar, & Pillar, 2009). For children with hearing loss, however, sleep is not the only factor nor may it be the primary factor affecting academic performance. Evidence exists that children with hearing loss expend greater listening effort than their peers with normal hearing (Bess, Dodd-Murphy, & Parker, 1998; Hicks & Tharpe, 2002; McGarrigle, Gustafson, Hornsby, & Bess, 2019; Stelmachowicz, Lewis, Choi, & Hoover, 2007). This translates to greater fatigue, stress and increased academic risk for children with hearing loss—even children with milder degrees of hearing loss than those presenting for cochlear implant candidacy (Bess et al., 1998; Tharpe, 2008). Children with hearing loss, who do not meet the typical auditory profile for cochlear implant candidacy, not only demonstrate speech recognition benefits from cochlear implantation, but may also experience decreased listening effort, fatigue, stress, and associated academic risk. Thus, a clinical measure of listening effort may ultimately become a part of the pediatric battery for implant candidate assessment (Figure 10–2).



FIGURE 10–2. Auditory-based instruction is a vital part of a child's classroom experience. The effects of childhood hearing loss on listening effort and mental alertness can greatly impact learning and academic performance.

Older Adults and Listening Effort

Age is known to affect a host of cognitive processes including working memory (Salthouse, 1991, 1994; Span, Ridderinkhof, & van der Molen, 2004) and executive function (Buckner, 2004; Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010; Span et al., 2004). Thus, it is not completely unexpected that older listeners have been shown to expend greater listening effort for speech recognition in noise than younger listeners (Anderson, Nelson, Kreft, Nelson, & Oxenham, 2011; Cramer & Donai, 2019; Meister, Rahlmann, Lemke, & Besser, 2018; Sommers & Phelps, 2016). This is thought to be related to the effect of age on global cognitive processing. In a similar vein, but from an auditory perspective, older individuals—*even those with normal hearing*—exhibit significantly poorer speech recognition in noise (Buss, Hodge, Calandruccio, Leibold, & Grose, 2018; Dubno, Horwitz, & Ahlstrom, 2002, 2003; Gifford, Bacon, & Williams, 2007; Smith, Pichora-Fuller, Wilson, & MacDonald, 2012; Venezia, Martin, Hickok, & Richards, 2019). These age-related declines in speech recognition in noise are thought to be related to cognitive processing as well as age-related declines in auditory temporal processing.

Relationships between age, cognitive processing, hearing loss, and speech recognition in noise are likely also entwined with the increased risk for incident dementia in older individuals (see section entitled "Risk for Cognitive Decline" and "Dementia and Link with Hearing Loss"). Just as discussed in the previous section on children, it is possible that clinical testing for degree of listening effort may ultimately assist adult implant candidate selection—especially for older adults who may be considered "borderline" candidates.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

MULTISENSORY ASSESSMENT

Assessment of speech recognition both pre- and postoperatively involves the use of recorded speech stimuli presented in the sound field via audition only. Though this currently represents the standard of care assessment of speech rec-

ognition in clinical audiology, it is not a real-life assessment of communication abilities, as we are rarely placed in situations during which all visual cues are absent. In fact, audiovisual integration is a significant part of communication, as the majority of patients with whom we will work will have access to multiple sensory modalities for communication. For children with hearing loss, audiovisual integration is acquired via extensive early listening and communication experience.

Despite the audiovisual nature of speech communication, clinical practice has almost exclusively focused on speech testing in the auditory only condition. The reason has primarily been to gauge listeners' abilities to understand speech in the most challenging condition. Clinical measures of audiovisual speech recognition already exist for both children and adults. For pediatric multimodal speech perception testing, there is the Children's Audio-Visual Enhancement Test (CAVET; Tye-Murray & Geers, 2001), the Audiovisual Feature Test (Tyler et al., 1991), and the Multimodal Lexical Sentence Test for children (MLST-C; Holt, Kirk, & Hay-McCutcheon, 2011; Kirk et al., 2012), which was adapted from the unisensory Lexical Sentence Test (Eisenberg, Martinez, Holowecky, & Pogorelsky, 2002). All tests allow for auditory alone, visual alone, and audiovisual administration of stimuli. The CAVET is an open-set test of word recognition and includes three lists of 20 words. The Audiovisual Feature Test is a closed-set test that assesses recognition of consonant features. The MLST-C is an open-set test of sentence recognition, including 21 lists of eight sentences with 10 talkers and three key words per sentence. The MLST-C was also adapted for use in adults as the MLST-A (Kirk et al., 2012; Miller et al., 2017). The MLST-A and MLST-C are both available through GN Otometrics through the Astera audiometer platform.

We can be certain that as the field evolves, that the assessment of the whole child—including multimodal speech perception abilities—will likely be integrated into our clinical assessment batteries. We may even find that we want to assess preoperative visual-alone performance, as there are a number of studies documenting that individuals with hearing loss demonstrate enhanced visual motion detection (Bavalier, Dye, & Hauser, 2006; Shiell, Champoux, & Zatorre, 2014), speechreading abilities (Rouger et al., 2007; Tye-Murray, Hale, Spehar, Myerson, & Sommers, 2014), and visual temporal processing (Butera et al., 2018; Nava, Bottari, Zampini, & Pavani, 2008). Furthermore, there is some evidence that visual processing may be related to postoperative auditory outcomes for adult cochlear implant recipients (Doucet, Bergeron, Lassonde, Ferron, & Lepore, 2006; Jahn, Stevenson, & Wallace, 2017).

STRUCTURAL AND FUNCTIONAL NEUROIMAGING

Structural neuroimaging provides information about anatomical structures including soft tissue (e.g., magnetic resonance imaging [MRI], diffusion tensor imaging [DTI]) and bony tissue (e.g., x-ray, computed tomography [CT]). Functional neuroimaging provides information about neural activity in response to sensory stimuli including electroencephalography (EEG), functional MRI (fMRI), magnetoencephalography (MEG), and functional near infrared spectroscopy (fNIRS). While a detailed description and comparison of neuroimaging techniques are beyond the scope of this text, we will focus on studies which have utilized structural and functional neuroimaging as a means of explaining postoperative variability in cochlear implant outcomes.

Cross-modal plasticity is known to occur in the presence of sensory losses, such as hearing loss. Cross-modal plasticity occurs when deprivation or alteration in one sensory system, such as hearing loss, yields functional differences in other sensory systems (e.g., vision, somatosensation). A number of studies have documented the use of EEG, MEG, and fNIRS to quantify cross-modal reorganization for individuals with hearing loss resulting in auditory cortical structures responding to visual stimulation (Campbell & Sharma, 2014, 2016; L. C. Chen, Sandmann, Thorne, Bleichner, & Debener, 2016; Dewey & Hartley, 2015; Doucet et al., 2006; Fine, Finney, Boynton, & Dobkins, 2005; Finney, Clementz, Hickok, & Dobkins, 2003; Finney, 2001; Glick & Sharma, 2017; Sandmann et al., 2012; Sharma, A., Campbell, J., & Cardon, 2015; Sharma, Gilley, Dorman, &

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Baldwin, 2007; Stropahl & Debener, 2017) as well as somatosensory stimulation (Cardon & Sharma, 2018; Glick & Sharma, 2016; Sharma, Campbell, & Cardon, 2015; Sharma et al., 2016).

Although a number of studies have documented that cross-modal reorganization resulting from hearing loss is at least somewhat reversible following cochlear implantation (Sharma et al., 2016), cross-modal reorganization following hearing loss has been shown to be maladaptive in many cases. Maladaptive plasticity refers to the cross-modal reorganization negatively impacting unisensory function for impoverished modality. A number of studies have documented that cross-modal reorganization—or visual takeover of auditory and auditory association cortices—was negatively associated with auditory-only speech recognition with a cochlear implant (L. C. Chen, Puschmann, & Debener, 2017; L. C. Chen, Sandmann, Thorne, Bleichner, & Debener, 2016; Doucet et al., 2006; Liang et al., 2017; Sandmann et al., 2012; Sharma, Campbell, & Cardon, 2015). However, there are a few studies that have either found no negative effects of cross-modal reorganization, or even positive adaptive effects (Anderson, Wiggins, Kitterick, & Hartley, 2017; Rouger et al., 2012; Strelnikov et al., 2013); the inconsistency in findings provides motivation for additional research, particularly given the potential clinical application of this measure as a predictive value for postoperative outcomes.

Indeed some researchers have been incorporating measures of structural and functional neuroimaging prior to implantation and have documented (1) degree of visual takeover of auditory cortical areas is a significant predictor for postoperative auditory outcomes (Han, Lee, Kang, Oh, & Lee, 2019), (2) preoperative morphological changes in auditory neural areas are correlated with poorer postoperative outcomes with cochlear implantation (Feng et al., 2018), and, (3) DTI-based preoperative connectivity in auditory and auditory association areas is correlated with postoperative auditory outcomes with cochlear implantation in children (Chang, Hee, Paik, Lee, & Lee, 2012; Huang et al., 2015; Wu et al., 2016). Thus, we may ultimately investigate structural and functional neuroimaging prior to implantation as a means to help predict postoperative auditory outcomes. As it stands today, we have little information in the preoperative time period to provide a reasonable prediction about postoperative outcomes for adults and children.

BILATERAL IMPLANT CANDIDACY: WHEN IS IT TIME TO CONSIDER A SECOND IMPLANT?

One of the most frequently asked questions from both clinicians and patients is, "When is the right time to consider a second implant?" Despite the wealth of published research on both bimodal and bilateral function, there are currently no well-defined guidelines that can direct clinicians who are assisting with or recommending such decisions. More specifically, there are no definitive reports highlighting audiometric profiles, configuration of hearing loss, levels of speech perception performance, or levels of speech/language delay that can serve as preoperative indicators to determine whether an individual should pursue one or two implants.

Most patients being considered for cochlear implantation will retain "bilateral" hearing in the sense that they will either hear bimodally—with one cochlear implant and aided acoustic hearing in the no-implanted ear—or will receive two cochlear implants. Bilateral cochlear implantation is considered standard of care treatment for individuals with bilateral severe-to-profound sensorineural hearing loss for most private health insurance companies in the United States. Further the William House Cochlear Implant Study Group (Balkany et al., 2008) and the British Cochlear Implant Group (BCIG; 2008) have recognized bilateral cochlear implantation as accepted medical practice and stated that it should be considered standard of care treatment for severe-to-profound sensorineural hearing loss. Indeed a number of studies have documented that cost effectiveness of bilateral cochlear implantation across a number of countries and payer models (Bichey & Miyamoto, 2008; J. M. Chen, Amoodi, & Mittmann, 2014; Foteff et al., 2016; Ontario, 2018); however,

STUDENTS-HUB.com Uploaded By: tuka abuzneid

other studies have demonstrated better cost effectiveness of bimodal stimulation as compared to both unilateral or bilateral cochlear implantation (Theriou, Fielden, & Kitterick, 2019) or have demonstrated cost effectiveness of bilateral cochlear implantation being dependent upon the variability of patient outcomes (Bond et al., 2009).

In order to make data-driven recommendations for a second implant, one must recognize that the efficacy of a particular intervention—in this case, a second cochlear implant—depends heavily on the tests used. Such tests must be sensitive enough to gauge the relevant speech information provided by acoustic hearing in the case of bimodal hearing, as well as the information provided by a second cochlear implant for bilateral implant recipients. This is much easier said than done.

For children acquiring spoken language via implant technology, there are an increasing number of reports indicating that bilateral cochlear implantation—at a young age—yields higher levels of speech perception (Lovett, Kitterick, Hewitt, & Summerfield, 2010; Wolfe et al., 2007), rapid language acquisition achieving age-appropriate norms at younger ages (Wie, 2010, but see Boons et al., 2012), binaural summation (Sheffield, Haynes, Wanna, Labadie, & Gifford, 2015), equivalent head shadow across ears (Buss et al., 2008; Gifford, Dorman, Sheffield, Teece, & Olund, 2014; Litovsky, Parkinson, Arcaroli, & Sammeth, 2006; Sheffield et al., 2015), binaural squelch (Adunka, Buss, Clark, Pillsbury, & Buchman, 2008; Eapen, Buss, Adunka, Pillsbury III, & Buchman, 2009), symmetry of brainstem auditory pathway maturation (Easwar, Yamazaki, Deighton, Papsin, & Gordon, 2017; Gordon, Henkin, & Kral, 2015; Polonenko, Papsin, & Gordon, 2015, 2017, 2018), improved listening effort (Hughes & Galvin, 2013), and improved localization abilities (Beijen, Snik, & Mylanus, 2007; Godar & Litovsky, 2010; Grieco-Calub & Litovsky, 2010; Lovett et al., 2010; Van Deun et al., 2010).

Recently we demonstrated that adult bimodal listeners and bilateral cochlear implant recipients achieve similar outcomes on clinical measures of speech recognition (Gifford & Dorman, 2019), whereas more complex, laboratory-based measures may be better suited for identifying bilateral candidates. Although laboratory-based assessments will likely not be routinely used in a clinical environment, we can still strive to identify measures that are both clinically efficient and sensitive to differences between bilateral recipients and bimodal listeners. Assessments, including the "whole patient," will likely be required in order to determine bilateral candidacy and for determining efficacy of bilateral cochlear implantation, as the current clinical measures of speech perception, as well as speech and language outcomes, are not sensitive to the effects of unilateral versus bilateral deafness. This is a fact that has been clearly outlined in the literature on minimal hearing loss (Bess & Tharpe, 1984, 1986; R. Oyler, A. Oyler, & Matkin, 1988; Tharpe, 2008; Tharpe & Bess, 1991). In other words, as long as a single implant provides significant communicative improvement, standardized measures of speech perception and speech/language development will likely not provide the information needed to determine candidacy nor to assess postoperative effectiveness of bilateral implantation. Thus, we will likely see more widespread clinical use of complex listening tasks, including multiple loudspeakers, such as that shown with the R-SPACE™ system in Figure 10–3.



FIGURE 10–3. The R-SPACE™ array of eight loudspeakers delivers proprietary restaurant noise recordings from all speakers allowing for the assessment of speech recognition in a realistic listening environment—one in which noise originates from all around the listener rather than a single loudspeaker placed in front, to the side, or to the back of the listener.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

SUMMARY

As clinicians, we must strive to constantly challenge the status quo regarding standard of care and question whether our current tools are enough to identify patient concerns, to identify patients who may continue to struggle with communication in everyday listening environments, and to identify the *global* effectiveness of a particular treatment option. The latter concern, in particular, will certainly be considered by insurance and governmental agencies when proposing health care initiatives for cost containment. Though the field has made considerable strides in the management and assessment of patients of significant hearing loss, we still have much room for improvement.

Cochlear implants have been called the most successful neural prosthesis ever developed, and for this reason, cochlear implants may serve as a metaphorical blueprint in the development of other neural prosthetics, such as those for the vestibular and visual system (Wilson & Dorman, 2008). For clinicians who work with cochlear implant recipients, there is simply no other intervention in this field that yields such dramatic, life-altering outcomes. It is for this reason that we must continue to promote public awareness and eliminate barriers to this technology for those who may derive benefit. The future holds tremendous promise for adults and children with significant sensorineural hearing loss with our continued attention, research, assessment, and reassessment of our clinical management protocols, the possibilities will most certainly multiply.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

REFERENCES

Adunka, O., Buss, E., Clark, M., Pillsbury, H. C., & Buchman, C. A. (2008). Effect of preoperative residual hearing on speech perception after cochlear implantation. *Laryngoscope*, *118*, 2044–2049.

Ahern, S., & Beatty, J. (1979). Pupillary responses during information processing vary with Scholastic Aptitude Test scores. *Science*, *205*(4412), 1289–1292.

Alhanbali, S., Dawes, P., Lloyd, S., & Munro, K. J. (2017). Self-reported listening-related effort and fatigue in hearing-impaired adults. *Ear & Hearing*, *38*(1), e39–e48.

Alhanbali, S., Dawes, P., Lloyd, S., & Munro, K. J. (2018). Hearing handicap and speech recognition correlate with self-reported listening effort and fatigue. *Ear & Hearing*, *39*(3), 470–474. https://doi.org/10.1097/AUD.0000000000000515

Ambert-Dahan, E., S., R., Marot, L., Bouccara, D., Sterkers, O., Ferrary, E., & Mosnier, I. (2017). Cognitive evaluation of cochlear implanted adults using CODEX and MoCA Screening Tests. *Otology & Neurotology*, *38*(8), e282–e284. https://doi.org/10.1097/MAO.0000000000001464

Anderson, E. S., Nelson, D. a, Kreft, H., Nelson, P. B., & Oxenham, A. J. (2011). Comparing spatial tuning curves, spectral ripple resolution, and speech perception in cochlear implant users. *The Journal of the Acoustical Society of America*, *130*(1), 364–375. https://doi.org/10.1121/1.3589255

Anderson, C. A., Wiggins, I. M., Kitterick, P. T., & Hartley, D. E. (2017). Adaptive benefit of cross-modal plasticity following cochlear implantation in deaf adults. *Proceedings of the National Academy of Sciences*, *114*(38), 10256–10261. https://doi.org/10.1073/pnas.1704785114

AuBuchon, A. M., Pisoni, D. B., & Kronenberger, W. G. (2015). Verbal processing speed and executive functioning in long-term cochlear implant users. *Journal of Speech, Language and Hearing Research*, *58*, 151–162.

Balkany, T., Hodges, A., Telischi, F., Hoffman, R., Madell, J., Parisier, S., & Litovsky, R. (2008). William House Cochlear Implant Study Group: Position statement on bilateral cochlear implantation. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *29*(2), 107.

Bavalier, D., Dye, M. W. G., & Hauser, P. C. (2006). Do deaf individuals see better? *Trends in Cognitive Science*, *10*(11), 512–518.

Beck, D. L., Weinstein, B. R., & Harvey, M. (2018). Dementia screening: A role for audiologists. *Hearing Review*, *25*(7), 36–39.

Beijen, J. W., Snik, A. F., & Mylanus, E. A. (2007). Sound localization ability of young children with bilateral cochlear implants. *Otology & Neurotology*, *28*(4), 479–485.

Bess, F. H., Dodd-Murphy, J., & Parker, R. A. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear and Hearing*, *19*(5), 339–354.

Bess, F. H., & Tharpe, A. M. (1984). Unilateral hearing impairment in children. *Pediatrics*, *74*, 206–216.

Bess, F. H., & Tharpe, A. M. (1986). Case history data on unilaterally hearing-impaired children. *Ear and Hearing*, *7*(1), 14–19.

Bichey, B. G., & Miyamoto, R. T. (2008). Outcomes in bilateral cochlear implantation. *Otolaryngology-Head and Neck Surgery*, *138*(5), 655–661.

Bond, M., Mealing, S., Anderson, R., Elston, J., Weiner, G., Taylor, R. S., . . . Stein, K. (2009). The effectiveness and cost-effectiveness of cochlear implants for severe to profound deafness in children and adults: A systematic review and economic model. *Health Technology Assessment*, *13*(44), 1–330. https://doi.org/10.3310/hta13440

Boons, T., Brokx, J. P., Dhooge, I., Frijns, J. H., Peeraer, L., Vermeulen, A., . . . van Wieringen, A. (2012). Predictors of spoken language development following pediatric cochlear implantation. *Ear and Hearing*, *33*(5), 617–639.

British Cochlear Implant Group (BCIG) (2008). Position statement—bilateral cochlear implantation. Retrieved from http://www.bcig.org.uk/downloads/pdfs/BCIG position statement—Bilateral Cochlear Implantation May 07.pdf

Buckner, R. L. (2004). Memory and executive function in aging and AD: Multiple factors that cause decline and reserve factors that compensate. *Neuron*, *44*(1), 195–208.

Buss, E., Hodge, S. E., Calandruccio, L., Leibold, L. J., & Grose, J. H. (2018). Masked sentence recognition in children, young adults, and older adults: Age-dependent effects of semantic context and masker type. *Ear & Hearing*, *2018 Dec 2*. https://doi.org/10.1097/AUD.0000000000000692

Buss, E., Pillsbury, H. C., Buchman, C. A., Pillsbury, C. H., Clark, M. S., Haynes, D. S., & Novak, M. A. (2008). Multicenter U.S. bilateral MED-EL cochlear implantation study: Speech perception over the first year of use. *Ear and Hearing*, *29*(1), 20–32.

Butera, I. M., Stevenson, R. A., Mangus, B. D., Woynaroski, T. G., Gifford, R. H., & Wallace, M. T. (2018). Audiovisual temporal processing in postlingually deafened adults with cochlear implants. *Scientific Reports*, *8*(1), e11345. https://doi.org/10.1038/s41598-018-29598-x

Campbell, J., & Sharma, A. (2014). Cross-modal reorganization in adults with early stage hearing loss. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0090594

Campbell, J., & Sharma, A. (2016). Visual cross-modal re-organization in children with cochlear implants. *PLoS ONE*, *11*(1), 1–18. https://doi.org/10.1371/journal.pone.0147793

Cardin, V. (2016). Effects of aging and adult-onset hearing loss on cortical auditory regions. *Frontiers in Neuroscience*, *10*(May), 1–12. https://doi.org/10.3389/fnins.2016.00199

Cardon, G., & Sharma, A. (2018). Somatosensory cross-modal reorganization in adults with age-related, early-stage hearing loss. *Frontiers in Human Neuroscience*, *12*, 172. https://doi.org/10.3389/fnhum.2018.00172

Chang, Y., Hee, H. R., Paik, J. S., Lee, K. Y., & Lee, S. H. (2012). Voxel-wise analysis of diffusion tensor imaging for clinical outcome of cochlear implantation: Retrospective study. *Clinical and Experimental Otorhinolaryngology*, *5*(Suppl. 1), S37–S42. https://doi.org/10.3342/ceo.2012.5.S1.S37

Chen, J. M., Amoodi, H., & Mittmann, N. (2014). Cost-utility analysis of bilateral cochlear implantation in adults: A health economic assessment from the perspective of a publicly funded program. *Laryngoscope*, *124*, 1452–1458.

Chen, L. C., Puschmann, S., & Debener, S. (2017). Increased cross-modal functional connectivity in cochlear implant users. *Scientific Reports*, *7*(1), 10043. https://doi.org/10.1038/s41598-017-10792-2

Chen, L. C., Sandmann, P., Thorne, J. D., Bleichner, M. G., & Debener, S. (2016). Cross-modal functional reorganization of visual and auditory cortex in adult cochlear implant users identified with fNIRS. *Neural Plasticity*, *2016*, 1–13. https://doi.org/10.1155/2016/4382656

Claes, A. J., van de Heyning, P., Giles, A., Van Rompaey, V., & Mertens, G. (2018). Cognitive outcomes after cochlear implantation in older adults: A systematic review. *Cochlear Implants International*, *19*(5), 239–254. https://doi.org/10.1080/14670100.2018.1484328

Cosetti, M. K., Pinkston, J. B., Flores, J. M., Friedmann, D. R., Jones, C. B., Roland, J. T., & Waltzman, S. B. (2016). Neurocognitive testing and cochlear implantation: Insights into performance in older adults. *Clinical Interventions in Aging*, *11*, 603–613. https://doi.org/10.2147/CIA.S100255

Cramer, J. L., & Donai, J. J. (2019). Effects of signal bandwidth on listening effort in young- and middle-aged adults. *International Journal of Audiology*, *58*(2), 116–122. https://doi.org/10.1080/14992027.2018.153325

Davies, H. R., Cadar, D., Herbert, A., Orrell, M., & Steptoe, A. (2017). Hearing impairment and incident dementia: Findings from the English Longitudinal Study of Ageing. *Journal of the American Geriatric Society*, *65*(9), 2074–2081.

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., . . . Munro, K. J.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

(2015). Hearing loss and cognition: The role of hearing aids, social isolation and depression. *PLoS ONE*, *10*(3), e0119616. https://doi.org/10.1371/journal.pone.0119616

Deal, J. A., Betz, J., Yaffe, K., Harris, T., Purchase-Helzner, E., Satterfield, S., . . . Group., H. A. S. (2017). Hearing impairment and incident dementia and cognitive decline in older adults: The health ABC study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *72*(5), 703–709.

Deal, J. A., Reed, N. S., Kravetz, A. D., Weinreich, H., Yeh, C., Lin, F. R., & Altan, A. (2018). Incident hearing loss and comorbidity: A longitudinal administrative claims study. *JAMA Otolaryngology-Head & Neck Surgery*, *2018 Nov 8*. https://doi.org/10.1001/jamaoto.2018.2876

Dewey, R. S., & Hartley, D. E. (2015). Cortical cross-modal plasticity following deafness measured using functional near-infrared spectroscopy. *Hearing Research*, *325*, 55–63. https://doi.org/10.1016/j.heares.2015.03.007

Dorman, M. F., Spahr, A., Gifford, R. H., Cook, S., Zhang, T., Loiselle, L., . . . Schramm, D. (2012). Current research with cochlear implants at Arizona State University. *Journal of the American Academy of Audiology*, *23*(6), 385–395. https://doi.org/10.3766/jaaa.23.6.2

Doucet, M. E., Bergeron, F., Lassonde, M., Ferron, P., & Lepore, F. (2006). Cross-modal reorganization and speech perception in cochlear implant users. *Brain*, *129*(12), 3376–3383. https://doi.org/10.1093/brain/awl264

Downs, D. W. (1982). Effects of hearing aid use on speech discrimination and listening effort. *Journal of Speech and Hearing Disorders*, *47*(2), 189–193.

Dubno, J. R., Horwitz, A. R., & Ahlstrom, J. B. (2002). Benefit of modulated maskers for speech recognition by younger and older adults with normal hearing. *The Journal of the Acoustical Society of America*, *111*(6), 2897–2907.

Dubno, J. R., Horwitz, A. R., & Ahlstrom, J. B. (2003). Recovery from prior stimulation: Masking of speech by interrupted noise for younger and older adults with normal hearing. *The Journal of the Acoustical Society of America*, *113*(4), 2084–2094.

Eapen, R. J., Buss, E., Adunka, M. C., Pillsbury III, H. C., & Buchman, C. A. (2009). Hearing-in-noise benefits after bilateral simultaneous cochlear implantation continue to improve 4 years after implantation. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *30*(2), 153.

Easwar, V., Yamazaki, H., Deighton, M., Papsin, B., & Gordon, K. (2017). Cortical representation of interaural time difference is impaired by deafness in development: Evidence from children with early long-term access to sound through bilateral cochlear implants provided simultaneously. *The Journal of Neuroscience*, 2538–16. https://doi.org/10.1523/JNEUROSCI.2538-16.2017

Eisenberg, L. S., Martinez, A. S., Holowecky, S. R., & Pogorelsky, S. (2002). Recognition of lexically controlled words and sentences by children with normal hearing and children with cochlear implants. *Ear and Hearing*, *23*(5), 450–462.

Eliasson, A., Eliasson, A., King, J., Gould, B., & Eliasson, A. (2002). Association of sleep and academic performance. *Sleep and Breathing*, *6*(1), 45–48.

Feng, G., Ingvalson, E. M., Grieco-Calub, T. M., Roberts, M. Y., Ryan, M. E., Birmingham, P., . . . Wong, P. C. M. (2018). Neural preservation underlies speech improvement from auditory deprivation in young cochlear implant recipients. *Proceedings of the National Academy of Sciences*, *115*(5), E1022–E1031. https://doi.org/10.1073/pnas.1717603115

Ferri, C. P., Prince, M., Brayne, C., Brodaty, H., Fratiglioni, L., Ganguli, M., & Jorm, A. (2005). Global prevalence of dementia: A Delphi consensus study. *The Lancet*, *366*(9503), 2112–2117.

Feuerstein, J. F. (1992). Monaural versus binaural hearing: Ease of listening, word recognition, and attentional effort. *Ear and Hearing*, *13*(2), 80–86.

Fine, I., Finney, E., Boynton, G., & Dobkins, K. R. (2005). Comparing the effects of auditory deprivation and sign language within the auditory and visual cortex. *Journal of Cognitive Neuroscience*, *17*, 1621–1637.

Finney, E. M., Clementz, B. A., Hickok, G., & Dobkins, K. R. (2003). Visual stimuli activate auditory cortex in deaf subjects: evidence from MEG. *Neuroreport*, *14*(11), 1425–1427.

Finney, E. M. F. (2001). Visual stimuli activate auditory cortex in the deaf. *Nature Neuroscience*, *4*(12), 1171. https://doi.org/10.1038/nn763

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198.

Foteff, C., Kennedy, S., Milton, A. H., Deger, M., Payk, F., & Sanderson, G. (2016). Cost–Utility analysis of cochlear implantation in Australian adults. *Otology & Neurotology*, *37*(5), 454–461. https://doi.org/10.1097/MAO.0000000000000999

Fraser, S., Gagné, J. P., Alepins, M., & Dubois, P. (2010). Evaluating the effort expended to understand speech in noise using a dual-task paradigm: The effects of

STUDENTS-HUB.com Uploaded By: tuka abuzneid

providing visual speech cues. *Journal of Speech, Language, and Hearing Research*, *53*(1), 18–33.

Fritze, T., Teipel, S., Óvári, A., Kilimann, I., Witt, G., & Doblhammer, G. (2016). Hearing impairment affects dementia incidence: An analysis based on longitudinal health claims data in Germany. *PLoS One*, *11*(7), e0156876. https://doi.org/10.1371/journal.pone.0156876

Galvin, J. E., & Sadowsky, C. H. (2012). Practical guidelines for the recognition and diagnosis of dementia. *The Journal of the American Board of Family Medicine*, *25*(3), 367–382.

Gifford, R. H., Bacon, S. P., & Williams, E. J. (2007). An examination of speech recognition in a modulated background and of forward masking in younger and older listeners. *Journal of Speech, Language, and Hearing Research*, *50*(4), 857–858. https://doi.org/10.1044/1092-4388(2007/060)

Gifford, R. H., & Dorman, M. F. (2019). Bimodal hearing or bilateral cochlear implants? Ask the patient. *Ear & Hearing*, *40*(3), 501–516.

Gifford, R. H., Dorman, M. F., Sheffield, S. W., Teece, K., & Olund, A. P. (2014). Availability of binaural cues for bilateral implant recipients and bimodal listeners with and without preserved hearing in the implanted ear. *Audiology and Neurotology*, *19*(1). https://doi.org/10.1159/000355700

Glick, H., & Sharma, A. (2017). Cross-Modal plasticity in developmental and age-related hearing loss: Clinical implications. *Hearing Research*, *343*, 191–201. https://doi.org/10.1016/j.heares.2016.08.012

Godar, S. M., & Litovsky, R. Y. (2010). Experience with bilateral cochlear implants improves sound localization acuity in children. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *31*(8), 1287.

Golub, J. S., Luchsinger, J. A., Manly, J. J., Stern, Y., Mayeux, R., & Schupf, N. (2017). Observed hearing loss and incident dementia in a multiethnic cohort. *Journal of the American Geriatric Society*, *65*(8), 1691–1697.

Goman, A. M., & Lin, F. R. (2016). Prevalence of hearing loss by severity in the United States. *American Journal of Public Health*, *106*(10), 1820–1822.

Gordon, K., Henkin, Y., & Kral, A. (2015). Asymmetric hearing during development: The aural preference syndrome and treatment options. *Pediatrics*, *136*(1), 141–153. https://doi.org/10.1542/peds.2014-3520 [doi]

Gosselin, P. A., & Gagné, J. P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. *Journal of Speech, Language, and Hearing Research*, *54*(3), 944–958.

Gozal, D. (1998). Sleep-disordered breathing and school performance in children. *Pediatrics*, *102*(3), 616–620.

Granholm, E., Asarnow, R. F., Sarkin, A. J., & Dykes, K. L. (1996). Pupillary responses index cognitive resource limitations. *Psychophysiology*, *33*(4), 457–461.

Grieco-Calub, T. M., & Litovsky, R. Y. (2010). Sound localization skills in children who use bilateral cochlear implants and in children with normal acoustic hearing. *Ear and Hearing*, *31*(5), 645.

Gurgel, R. K., Ward, P. D., Schwartz, S., Norton, M. C., Foster, N. L., & Tschanz, J. T. (2014). Relationship of hearing loss and dementia: A prospective, population-based study. *Otology & Neurotology*, *35*(5), 775–781. https://doi.org/10.1097/MAO.0000000000000313

Gustafson, S. J., Key, A. P., Hornsby, B. W., & Bess, F. H. (2018). Fatigue related to speech processing in children with hearing loss: Behavioral, subjective, and electrophysiological measures. *Journal of Speech Language and Hearing Research*, *61*(4), 1000–1011. https://doi.org/10.1044/2018_JSLHR-H-17-0314

Han, J. H., Lee, H. J., Kang, H., Oh, S. H., & Lee, D. S. (2019). Brain plasticity can predict the cochlear implant outcome in adult-onset deafness. *Frontiers in Human Neuroscience*, *13*, 38. https://doi.org/10.3389/fnhum.2019.00038

Hebert, L. E., Weuve, J., Scherr, P. A., & Evans, D. A. (2013). Alzheimer disease in the United States (2010–2050) estimated using the 2010 census. *Neurology*, *80*(19), 1778–1783.

Hétu, R., Riverin, L., Lalande, N., Getty, L., & St-Cyr, C. (1988). Qualitative analysis of the handicap associated with occupational hearing loss. *British Journal of Audiology*, *22*(4), 251–264.

Heydebrand, G., Hale, S., Potts, L., Gotter, B., & Skinner, M. (2007). Cognitive predictors of improvements in adults' spoken word recognition six months after cochlear implant activation. *Audiology and Neurotology*, *12*(4), 254–264.

Heywood, R., Gao, Q., Nyunt, M. S. Z., Feng, L., Chong, M. S., Lim, W. S., . . . Ng, T. P. (2017). Hearing loss and risk of mild cognitive impairment and dementia: Findings from the Singapore Longitudinal Ageing Study. *Dementia and Geriatric Cognitive Disorders*, *43*(5–6), 259–268.

Hicks, C. B., & Tharpe, A. M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. *Journal of Speech, Language, and Hearing Research*, *45*(3), 573–584.

Holder, J. T., Reynolds, S. M., Sunderhaus, L. W., & Gifford, R. H. (2018). Current profile of adults presenting for preoperative cochlear implant evaluation. *Trends in Hearing*, *22*, 1–6. https://doi.org/10.1177/2331216518755288

STUDENTS-HUB.com Uploaded By: Iuka abuzneid

Holt, R. F., Kirk, K. I., & Hay-McCutcheon, M. (2011). Assessing multimodal spoken word-in-sentence recognition in children with normal hearing and children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, *54*(2), 632–657.

Hornsby, B. W. (2013). The effects of hearing aid use on listening effort and mental fatigue associated with sustained speech processing demands. *Ear & Hearing*, *34*(5), 523–534. https://doi.org/10.1097/AUD.0b013e31828003d8

Hornsby, B. W., Gustafson, S. J., Lancaster, H., Cho, S. J., Camarata, S., & Bess, F. H. (2017). Subjective fatigue in children with hearing loss assessed using self- and parent-proxy report. *American Journal of Audiology*, *26*(3S), 393–407. https://doi.org/10.1044/2017_AJA-17-0007

Hornsby, B. W., & Kipp, A. M. (2016). Subjective fatigue and vigor in adults with hearing loss are driven by perceived hearing difficulties not degree of hearing loss. *Ear & Hearing*, *37*(1), e1–e10. https://doi.org/10.1097/AUD.0000000000000203

Hornsby, B. W., Werfel, K., Camarata, S., & Bess, F. H. (2014). Subjective fatigue in children with hearing loss: Some preliminary findings. *American Journal of Audiology*, *23*(1), 129–134. https://doi.org/10.1044/1059-0889(2013/13-0017)

Huang, L., Zheng, W., Wu, C., Wei, X., Wu, X., Wang, Y., & Zheng, H. (2015). Diffusion tensor imaging of the auditory neural pathway for clinical outcome of cochlear implantation in pediatric congenital sensorineural hearing loss patients. *PLoS ONE*, *10*(10), e0140643. https://doi.org/10.1371/journal.pone.0140643

Huddle, M. G., Goman, A. M., Kernizan, F. C., Foley, D. M., Price, C., Frick, K. D., & Lin, F. R. (2017). The economicimpact of adult hearing loss: A systematic review. *JAMA Otolaryngology—Head & Neck Surgery*, *143*(10), 1040–1048. https://doi.org/10.1001/jamaoto.2017.1243

Hughes, K. C., & Galvin, K. L. (2013). Measuring listening effort expended by adolescents and young adults with unilateral or bilateral cochlear implants or normal hearing. *Cochlear Implants International*, *14*(3), 121–129. https://doi.org/10.1179/1754762812Y.0000000009

Jahn, K. N., Stevenson, R. A., & Wallace, M. T. (2017). Visual temporal acuity is related to auditory speech perception abilities in cochlear implant users. *Ear and Hearing*, *38*(2), 236–243. https://doi.org/10.1097/AUD.0000000000000379

Jayakody, D. M. P., Friedland, P. L., Nel, E., Martins, R. N., Atlas, M. D., & Sohrabi, H. R. (2017). Impact of cochlear implantation on cognitive functions of older adults: Pilot test results. *Otology & Neurotology*, *38*(8), e289–e295. https://doi.org/10.1097/MAO.0000000000001502

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science*, *154*(3756), 1583–1585.

Kirk, K. I., Prusick, L., French, B., Gotch, C., Eisenberg, L. S., & Young, N. (2012). Assessing spoken word recognition in children who are deaf or hard of hearing: A translational approach. *Journal of the American Academy of Audiology*, *23*(6), 464–475. https://doi.org/10.3766/jaaa.23.6.8

Klingner, J., Tversky, B., & Hanrahan, P. (2011). Effects of visual and verbal presentation on cognitive load in vigilance, memory, and arithmetic tasks. *Psychophysiology*, *48*(3), 323–332.

Kramer, S. E., Kapetyn, T. S., Festen, J. M., & Kuik, D. J. (1997). Assessing aspects of auditory handicap by means of pupil dilation. *Audiology*, *36*, 155–164. https://doi.org/10.3109/00206099709071969

Kramer, S. E., Kapteyn, T. S., & Houtgast, T. (2006). Occupational performance: Comparing normally-hearing and hearing-impaired employees using the Amsterdam Checklist for Hearing and Work. *International Journal of Audiology*, *45*(9), 503–512.

Kronenberger, W. G., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning and speech-language skills following long-term use of cochlear implants. *Journal of Deaf Studies and Deaf Education*, *19*(4), 456–470. https://doi.org/10.1093/deafed/enu011

Kronenberger, W. G., Henning, S. C., Ditmars, A. M., Roman, A. S., & Pisoni, D. B. (2018). Verbal learning and memory in prelingually deaf children with cochlear implants. *International Journal of Audiology 2*, *57*(10), 746–754. https://doi.org/10.1080/14992027.2018

Kuiper, J. S., Zuidersma, M., Oude Voshaar, R. C., Zuidema, S. U., van den Heuvel, E. R., Stolk, R. P., & Smidt, N. (2015). Social relationships and risk of dementia: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Review*, *22*, 39–57. https://doi.org/10.1016/j.arr.2015.04.006

Liang, M., Zhang, J., Liu, J., Chen, Y., Cai, Y., Wang, X., … Zheng, Y. (2017). Visually evoked visual-auditory changes associated with auditory performance in children with cochlear implants. *Frontiers in Human Neuroscience*, *11*, 510. https://doi.org/10.3389/fnhum.2017.00510

Lin, F. R. (2012). Hearing loss in older adults: Who's listening? *JAMA*, *307*(11), 1147–1148.

Lin, F. R., Metter, E. J., O'brien, R. J., Resnick, S. M., Zonderman, A. B., & Ferrucci, L. (2011). Hearing loss and incident dementia. *Archives of Neurology*, *68*(2), 214–220.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Lin, V. Y., Chung, J., Callahan, B. L., Smith, L., Gritters, N., Chen, J. M., . . . Masellis, M. (2017). Development of cognitive screening test for the severely hearing impaired: Hearing-impaired MoCA. *Laryngoscope*, *127*(Suppl. 1), S4–S11. https://doi.org/10.1002/lary.26590

Lin, F. R., Niparko, J. K., & Ferrucci, L. (2011). Hearing loss prevalence in the United States. *Archives of Internal Medicine*, *171*(20), 1851–1853.

Litovsky, R., Parkinson, A., Arcaroli, J., & Sammeth, C. (2006). Simultaneous bilateral cochlear implantation in adults: A multicenter clinical study. *Ear and Hearing*, *27*(6), 714–731.

Livingston, G., Sommerlad, A., Orgeta, V., Costafreda, S. G., Huntley, J., Ames, D., . . . Mukadam, N. (2017). Dementia prevention, intervention, and care. *Lancet*, *390*(10113), 2673–2734. https://doi.org/10.1016/S0140-6736(17)31363-6

Lovett, R. E., Kitterick, P. T., Hewitt, C. E., & Summerfield, A. Q. (2010). Bilateral or unilateral cochlear implantation for deaf children: An observational study. *Archives of Disease in Childhood*, *95*(2), 107–112.

Lyxell, B., Andersson, J., Arlinger, S., Bredberg, G., Harder, H., & Rönnberg, J. (1996). Verbal information-processing capabilities and cochlear implants: Implications for preoperative predictors of speech understanding. *The Journal of Deaf Studies and Deaf Education*, *1*(3), 190–201.

Mackersie, C. L., & Cones, H. (2011). Subjective and psychophysiological indexes of listening effort in a competing-talker task. *Journal of the American Academy of Audiology*, *22*(2), 113–122.

Mackersie, C. L., & Kearney, L. (2017). Autonomic nervous system responses to hearing-related demand and evaluative threat. *American Journal of Audiology*, *26*(3S), 373–377. https://doi.org/10.1044/2017_AJA-16-0133

Mackersie, C. L., MacPhee, I. X., & Heldt, E. W. (2015). Effects of hearing loss on heart rate variability and skin conductance measured during sentence recognition in noise. *Ear & Hearing*, *36*(1), 145–154. https://doi.org/10.1097/AUD.0000000000000091

Mahishale, V. (2015). Ageing world: Health care challenges. *Journal of the Scientific Society*, *42*(3), 138–143.

Mahoney, J. R., Verghese, J., Goldin, Y., Lipton, R., & Holtzer, R. (2010). Alerting, orienting, and executive attention in older adults. *Journal of the International Neuropsychological Society*, *16*(5), 877–889.

Mattingly, J. K., Castellanos, I., & Moberly, A. C. (2018). Nonverbal reasoning as a contributor to sentence recognition outcomes in adults with cochlear implants. *Otology & Neurotology*, *39*, e956–e963.

McGarrigle, R., Gustafson, S. J., Hornsby, B. W., & Bess, F. H. (2019). Behavioral measures of listening effort in school-age children: Examining the effects of signal-to-noise ratio, hearing loss, and amplification. *Ear & Hearing*, *40*(2), 381–392. https://doi.org/10.1097/AUD.0000000000000623

Meister, H., Rahlmann, S., Lemke, U., & Besser, J. (2018). Verbal response times as a potential indicator of cognitive load during conventional speech audiometry with matrix sentences. *Trends in Hearing*, *22*, 1–11. https://doi.org/10.1177/2331216518793255

Meister, H., Schreitmuller, S., Ortmann, M., Rahlmann, S., & Walger, M. (2016). Effects of hearing loss and cognitive load on speech recognition with competing talkers. *Frontiers in Psychology*, *7*, 301. https://doi.org/10.3389/fpsyg.2016.00301

Miller, C. W., Stewart, E. K., Wu, Y. H., Bishop, C., Bentler, R. A., & Tremblay, K. (2017). Working memory and speech recognition in noise under ecologically relevant listening conditions: Effects of visual cues and noise type among adults with hearing loss. *Journal of Speech Language and Hearing Research*, *60*(8), 2310–2320. https://doi.org/10.1044/2017_JSLHR-H-16-0284

Moberly, A. C., Castellanos, I., & Mattingly, J. K. (2018). Neurocognitive factors contributing to cochlear implant candidacy. *Otology & Neurotology*, *39*(10), e1010–e1018. https://doi.org/10.1097/MAO.0000000000002052

Moran, W. P., Zapka, J., Iverson, P. J., Zhao, Y., Wiley, M. K., Pride, P., & Davis, K. S. (2012). Aging Q3: An initiative to improve internal medicine residents' geriatrics knowledge, skills, and clinical performance. *Academic Medicine*, *87*(5), 635–642.

Mosnier, I., Bebear, J. P., Marx, M., Fraysse, B., Truy, E., Lina-Granade, G., . . . Sterkers, O. (2015). Improvement of cognitive function after cochlear implantation in elderly patients. *JAMA Otolaryngology-Head & Neck Surgery*, *141*(5), 442–450. https://doi.org/10.1001/jamaoto.2015.129

Mosnier, I., Vanier, A., Bonnard, D., Lina-Granade, G., Truy, E., Bordure, P., . . . Belmin, J. (2018). Long-term cognitive prognosis of profoundly deaf older adults after hearing rehabilitation using cochlear implants. *Journal of the American Geriatrics Society*, *66*(8), 1553–1561. https://doi.org/10.1111/jgs.15445

Nachtegaal, J., Festen, J. M., & Kramer, S. E. (2012). Hearing ability in working life and its relationship with sick leave and self-reported work productivity. *Ear and Hearing*, *33*(1), 94–103.

Nachtegaal, J., Kuik, D. J., Anema, J. R., Goverts, S. T., Festen, J. M., & Kramer, S. E. (2009). Hearing status, need for recovery after work, and psychosocial work characteristics: Results from an internet-based

STUDENTS-HUB.com Uploaded By: Iuka abuzneid

national survey on hearing. *International Journal of Audiology*, *48*(10), 684–691.

Nachtegaal, J., Smit, J. H., Smits, C. A. S., Bezemer, P. D., Van Beek, J. H., Festen, J. M., & Kramer, S. E. (2009). The association between hearing status and psychosocial health before the age of 70 years: Results from an Internet-based national survey on hearing. *Ear and Hearing*, *30*(3), 302–312.

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society Society*, *53*(4), 695–699.

Nava, E., Bottari, D., Zampini, M., & Pavani, F. (2008). Visual temporal order judgment in profoundly deaf individuals. *Experimental Brain Research*, *190*(2), 179–188.

Ontario, H. Q. (2018). Bilateral cochlear implantation: A health technology assessment. *Ontario Health Technology Assessment Series*, *18*(6), 1–139.

Oyler, R. F., Oyler, A. L., & Matkin, N. D. (1988). Unilateral hearing loss: Demographics and educational impact. *Language, Speech, and Hearing Services in Schools*, *19*(2), 201–210.

Peele, J. E., Troiani, V., Grossman, M., & Wingfield, A. (2011). Hearing loss in older adults affects neural systems supporting speech comprehension. *Journal of Neuroscience*, *31*(35), 12638–12643.

Peele, J. E., Troiani, V., Wingfield, A., & Grossman, M. (2010). Neural processing during older adults' comprehension of spoken sentences: Age differences in resource allocation and connectivity. *Cerebral Cortex*, *20*(4), 773–782. https://doi.org/10.1093/cercor/bhp142

Perez-Chada, D., Perez-Lloret, S., Videla, A. J., Cardinali, D., Bergna, M. A., Fernández-Acquier, M., & Drake, C. (2007). Sleep disordered breathing and daytime sleepiness are associated with poor academic performance in teenagers. A study using the Pediatric Daytime Sleepiness Scale (PDSS). *Sleep*, *30*(12), 1698–1703.

Pichora-Fuller, M. K. (2007). Audition and cognition: What audiologists need to know about listening. *Hearing Care for Adults* (pp. 71–85). Stafa, Switzerland: Phonak.

Picou, E. M., Ricketts, T. A., & Hornsby, B. W. (2011). Visual cues and listening effort: Individual variability. *Journal of Speech Language and Hearing Research*, *54*(5), 1416–1430. https://doi.org/10.1044/1092-4388(2011/10-0154)

Piquado, T., Isaacowitz, D., & Wingfield, A. (2010). Pupillometry as a measure of cognitive effort in younger and older adults. *Psychophysiology*, *47*(3), 560–569.

Pisoni, D. B. (2000). Cognitive factors and cochlear implants: Some thoughts on perception, learning, and memory in speech perception. *Ear and Hearing*, *21*(1), 70.

Polonenko, M. J., Papsin, B. C., & Gordon, K. A. (2015). The effects of asymmetric hearing on bilateral brainstem function: Findings in children with bimodal (electric and acoustic) hearing. *Audiology & Neuro-Otology*, *20*(Suppl. 1), 13–20.

Polonenko, M. J., Papsin, B. C., & Gordon, K. A. (2017). Delayed access to bilateral input alters cortical organization in children with asymmetric hearing. *NeuroImage Clinical*, *17*, 415–425.

Polonenko, M. J., Papsin, B. C., & Gordon, K. A. (2018). Limiting asymmetric hearing improves benefits of bilateral hearing in children using cochlear implants. *Scientific Reports*, *8*(1), 13201. https://doi.org/10.1038/s41598-018-31546-8.

Prince, M., & Jackson, J. (2009). *Alzheimer's Disease International. World Alzheimer Report 2009*.

Ravid, S., Afek, I., Suraiya, S., Shahar, E., & Pillar, G. (2009). Kindergarten children's failure to qualify for first grade could result from sleep disturbances. *Journal of Child Neurology*, *24*(7), 816–822.

Ray, J., Popli, G., & Fell, G. (2018). Association of cognition and age-related hearing impairment in the English Longitudinal Study of Ageing. *JAMA Otolaryngology-Head & Neck Surgery*, *144*(10), 876–882. https://doi.org/10.1001/jamaoto.2018.1656

Rönnberg, J., Rudner, M., Foo, C., & Lunner, T. (2008). Cognition counts: A working memory system for ease of language understanding (ELU). *International Journal of Audiology*, *47*, S99–S105.

Rossi-Katz, J., & Arehart, K. H. (2011). Survey of audiologic service provision to older adults with cochlear implants. *American Journal of Audiology*, *20*(2), 84–89.

Rouger, J., Lagleyre, S., Demonet, J. F., Fraysse, B., Deguine, O., & Barone, P. (2012). Evolution of crossmodal reorganization of the voice area in cochlear-implanted deaf patients. *Human Brain Mapping*, *33*, 1929–1940. https://doi.org/10.1002/hbm.21331

Rouger, J., Lagleyre, S., Fraysse, B., Deneve, S., Deguine, O., & Barone, P. (2007). Evidence that cochlear-implanted deaf patients are better multisensory integrators. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(17), 7295–7300. https://doi.org/10.1073/pnas.0609419104

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science*, *2*(3), 179–183.

Salthouse, T. A. (1994). The aging of working memory. *Neuropsychology*, *8*(4), 535–543.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Sandmann, P., Dillier, N., Eichele, T., Meyer, M., Kegel, A., Pascual-Marqui, R. D., . . . Debener, S. (2012). Visual activation of auditory cortex reflects maladaptive plasticity in cochlear implant users. *Brain*, *135*(2), 555–568. https://doi.org/10.1093/brain/awr329

Sharma, A., Campbell, J., & Cardon, G. (2015). Developmental and cross-modal plasticity in deafness: Evidence from the P1 and N1 event related potentials in cochlear implanted children. *International Journal of Psychophysiology*, *95*(2), 135–144. https://doi.org/10.1016/j.ijpsycho.2014.04.007

Sharma, A., Gilley, P. M., Dorman, M. F., & Baldwin, R. (2007). Deprivation-induced cortical reorganization in children with cochlear implants. *International Journal of Audiology*, *46*(9), 494–499.

Sharma, A., Glick, H., Campbell, J., Torres, J., Dorman, M., & Zeitler, D. M. (2016). Cortical plasticity and reorganization in pediatric single-sided deafness pre- and postcochlear implantation: A case study. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *37*(2), e26–34. https://doi.org/10.1097/MAO.0000000000000904

Sheffield, S. W., Haynes, D. S., Wanna, G. B., Labadie, R. F., & Gifford, R. H. (2015). Availability of binaural cues for pediatric bilateral cochlear implant recipients. *Journal of the American Academy of Audiology*, *26*(3). https://doi.org/10.3766/jaaa.26.3.8

Shiell, M. M., Champoux, F., & Zatorre, R. J. (2014). Enhancement of visual motion detection thresholds in early deaf people. *PLoS ONE*, *9*(2), e90498.

Shinn-Cunningham, B. G., & Best, V. (2008). Selective attention in normal and impaired hearing. *Trends in Amplification*, *12*(4), 283–299.

Simmons, B. B., Hartmann, B., & Dejoseph, D. (2011). Evaluation of suspected dementia. *American Academy of Family Physicians*, *84*(8), 895–902.

Smith, S. L., Pichora-Fuller, M. K., Wilson, R. H., & MacDonald, E. N. (2012). Word recognition for temporally and spectrally distorted materials: The effects of age and hearing loss. *Ear and Hearing*, *33*(3), 349–366.

Smith, G. N. L., Pisoni, D. B., & Kronenberger, W. G. (2018). High-variability sentence recognition in long-term cochlear implant users: Associations with rapid phonological coding and executive functioning. *Ear & Hearing, 2018 Dec 3*. https://doi.org/10.1097/AUD.0000000000000691

Sommers, M. S., & Phelps, D. (2016). Listening effort in younger and older adults: A comparison of auditory-only and auditory-visual presentations. *Ear & Hearing*, *37*(Suppl. 1), 62S–68S. https://doi.org/10.1097/AUD.0000000000000322

Sonnet, M. H., Montaut-Verient, B., Niemier, J. Y., Hoen, M., Ribeyre, L., & Parietti-Winkler, C. (2017). Cognitive abilities and quality of life after cochlear implantation in the elderly. *Otology & Neurotology*, *38*(8), e296–e301. https://doi.org/10.1097/MAO.0000000000001503

Span, M. M., Ridderinkhof, K. R., & van der Molen, M. W. (2004). Age-related changes in the efficiency of cognitive processing across the life span. *Acta Psychologica*, *117*(2), 155–183.

Stelmachowicz, P. G., Lewis, D. E., Choi, S., & Hoover, B. (2007). The effect of stimulus bandwidth on auditory skills in normal-hearing and hearing-impaired children. *Ear and Hearing*, *28*(4), 483–494.

Steven, R. A., Green, K. M., Broomfield, S. J., Henderson, L. A., Ramsden, R. T., & Bruce, I. A. (2011). Cochlear implantation in children with cerebral palsy. *International Journal of Pediatriac Otorhinolaryngology*, *75*(11), 1427–1430.

Strelnikov, K., Rouger, J., Demonet, J. F., Lagleyre, S., Fraysse, B., Deguine, O., & Barone, P. (2013). Visual activity predicts auditory recovery from deafness after adult cochlear implantation. *Brain*, *136*, 3682–3695. https://doi.org/10.1093/brain/awt274

Stropahl, M., & Debener, S. (2017). Auditory cross-modal reorganization in cochlear implant users indicates audio-visual integration. *NeuroImage Clinical*, *16*, 514–523. https://doi.org/10.1016/j.nicl.2017.09.001

Tay, T., Wang, J. J., Kifley, A., Lindley, R., Newall, P., & Mitchell, P. (2006). Sensory and cognitive association in older persons: Findings from an older Australian population. *Gerontology*, *52*(6), 386–394.

Taylor, J. S. (1981). Pupillary response to auditory versus visual mental loading: A pilot study using super 8-mm photography. *Perceptual and Motor Skills*, *52*(2), 425–426.

Tharpe, A. M. (2008). Unilateral and mild bilateral hearing loss in children: Past and current perspectives. *Trends in Amplification*, *12*(1), 7–15.

Tharpe, A. M., & Bess, F. H. (1991). Identification and management of children with minimal hearing loss. *International Journal of Pediatric Otorhinolaryngology*, *21*(1), 41–50.

Theriou, C., Fielden, C. A., & Kitterick, P. T. (2019). The cost-effectiveness of bimodal stimulation compared to unilateral and bilateral cochlear implant use in adults with bilateral severe to profound deafness. *Ear & Hearing, 2019 April*. https://doi.org/10.1097/AUD.0000000000000727

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Tye-Murray, N. & Geers, A. (2001). *The Children's Audiovisual Enhancement Test (CAVET)*. St. Louis, MO: Central Institute for the Deaf.

Tye-Murray, N., Hale, S., Spehar, B., Myerson, J., & Sommers, M. S. (2014). Lipreading in school-age children: The roles of age, hearing status, and cognitive ability. *Journal of Speech Language and Hearing Research*, *57*(2), 556–565. https://doi.org/10.1044/2013_JSLHR-H-12-0273

Tyler, R. S., Fryauf-Bertschy, H., & Kelsay, D. (1991). *Audiovisual feature test for young children.* Iowa City, Iowa: University of Iowa.

United Nations, Department of Education and Social Affairs. (2017). World Population Prospects 2017.

Van Deun, L., Van Wieringen, A., Scherf, F., Deggouj, N., Desloovere, C., Offeciers, F. E., & Wouters, J. (2010). Earlier intervention leads to better sound localization in children with bilateral cochlear implants. *Audiology and Neuro-Otology*, *15*(1), 7–17.

Van Engen, K. J., & McLaughlin, D. J. (2018). Eyes and ears: Using eye tracking and pupillometry to understand challenges to speech recognition. *Hearing Research*, *369*, 56–66. https://doi.org/10.1016/j.heares.2018.04.013

Venezia, J. H., Martin, A. G., Hickok, G., & Richards, V. M. (2019). Identification of the spectrotemporal modulations that support speech intelligibility in hearing-impaired and normal-hearing listeners. *Journal of Speech Language and Hearing Research*, *62*(4), 1051–1067. https://doi.org/10.1044/2018_JSLHR-H-18-0045

Wie, O. B. (2010). Language development in children after receiving bilateral cochlear implants between 5 and 18 months. *International Journal of Pediatric Otorhinolaryngology*, *74*(11), 1258–1266.

Wilson, B. S., & Dorman, M. F. (2008). Cochlear implants: A remarkable past and a brilliant future. *Hearing Research*, *242*(1–2), 3–21.

Wingfield, A., Tun, P. A., & McCoy, S. L. (2005). Hearing loss in older adulthood: What it is and how it interacts with cognitive performance. *Current Directions in Psychological Science*, *14*(3), 144–148.

Winn, M. B., & Moore, A. N. (2018). Pupillometry reveals that context benefit in speech perception can be disrupted by later-occurring sounds, especially in listeners with cochlear implants. *Trends in Hearing*, *22*. doi: 10.1177/2331216518808962.

Wolfe, J., Baker, S., Caraway, T., Kasulis, H., Mears, A., Smith, J., & Wood, M. (2007). 1-year postactivation results for sequentially implanted bilateral cochlear implant users. *Otology & Neurotology*, *28*(5), 589–596.

Wong, A., Nyenhuis, D., Black, S. E., Law, L. S., Lo, E. S., Kwan, P. W., . . . Mok, V. (2015). Montreal Cognitive Assessment 5-minute protocol is a brief, valid, reliable, and feasible cognitive screen for telephone administration. *Stroke*, *46*(4), 1059–1064. https://doi.org/10.1161/STROKEAHA.114.007253

World Health Organization. (2018). Ageing and health. Retrieved May 17, 2019, from https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

Wu, C., Huang, L., Tan, H., Wang, Y., Zheng, H., Kong, L., & Zheng, W. (2016). Diffusion tensor imaging and MR spectroscopy of microstructural alterations and metabolite concentration changes in the auditory neural pathway of pediatric congenital sensorineural hearing loss patients. *Brain Research*, *1639*, 228–234. https://doi.org/10.1016/j.brainres.2014.12.025

Zekveld, A. A., George, E. L., Kramer, S. E., Goverts, S. T., & Houtgast, T. (2007). The development of the text reception threshold test: A visual analogue of the speech reception threshold test. *Journal of Speech, Language, and Hearing Research*, *50*(3), 576–584.

Zekveld, A. A., & Kramer, S. E. (2014). Cognitive processing load across a wide range of listening conditions: Insights from pupillometry. *Psychophysiology*, *51*(3), 277–284. https://doi.org/10.1111/psyp.12151

Zekveld, A. A., Kramer, S. E., & Festen, J. M. (2010). Pupil response as an indication of effortful listening: The influence of sentence intelligibility. *Ear and Hearing*, *31*(4), 480–490.

Zekveld, A. A., Kramer, S. E., & Festen, J. M. (2011). Cognitive load during speech perception in noise: The influence of age, hearing loss, and cognition on the pupil response. *Ear and Hearing*, *32*(4), 498–510.

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Index

Note: Page numbers in **bold** reference non-text material.

A

A-weighting, 16*n*1, 129*n*1
AAPS-4. *See* Arizona Articulation Proficiency Scale-Fourth Edition
Abbreviated Profile of Hearing Aid Benefit (APHAB), 24
Ability, 63
Academic skills, assessment, 70–71, **72–73**, 150–151
Acoustic hearing preservation, 127
Acoustic neuromas, 102
Adults
  candidate selection, 13–31
    audiologic evaluation, 13–14
    audiometric thresholds, 14, 28–29
    expansion of criteria, 93–94, **93**
    hearing aid verification, 17–18
    neurofibromatosis type 2 (NF2), 102
    social workers and psychologists in, 26–27
    speech-perception metrics, 15–16, **16**
    speech recognition criteria, **7–8**, 10
    speech-recognition testing, 14–24
  labeled indications, 6, **7–8**, 10
  postoperative assessment, 111–121
  postoperative medical management, 120–121
  prelingually deafened adolescents and adults, 98–100, **100**
Advanced Bionics (AB)
  adult implant criteria, 6, 14, 17
  EAS systems, 10
  HR90K Ultra and Ultra 3D, **9**
  pediatric implant criteria, 38, 40
  preoperative imaging, 50
  3D, 6, **7**
Age, cochlear implantation and, 28, 50–51
Aging population, 160
AHL. *See* Asymmetric hearing loss
Alexander Graham Bell Association for the Deaf and Hard of Hearing, 51
American Academy of Audiology, 17
  Guidelines for the Audiologic Management of Adult Hearing Impairment, 112, 113
  Pediatric Amplification Protocol, 47, 126, 128
ANSD. *See* Auditory neuropathy spectrum disorder
APHAB. *See* Abbreviated Profile of Hearing Aid Benefit
APT/HI-3. *See* Auditory Perception Test for the Hearing Impaired, Third Edition
Arizona Articulation Proficiency Scale-Fourth Edition (AAPS-4), **64**, 65, 147–148
Arndt, S., 98
ASC. *See* Auditory Skills Checklist
Assessment
  academic skills, 70–71, **72–73**
  of adults, 17–22
  of auditory skills, 69–70, **69**
  bilingual children, 71
  of children, 39–44, 61–74
  criterion-referenced assessments, 62, 65, 66, 70, 71, 147, 150
  of language, 65–66, **67–68**, 68–69
  for non-English speaking recipients, 118–119
  norm-referenced assessments, 62, 66, 71, 146–147
  postoperative assessment, adults, 111–121

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Assessment *(continued)*
of special populations, 71, 73
speech perception, 69–70
of speech production, 63–65
standardized assessments, 61–62
See also Audiologic evaluation; Speech-recognition testing
Assessment instruments
Abbreviated Profile of Hearing Aid Benefit (APHAB), 24
Arizona Articulation Proficiency Scale-Fourth Edition (AAPS-4), **64**, 65, 147–148
Audiovisual Feature Test, 167
Auditory Perception Test for the Hearing Impaired, Third Edition (APT/HI-3), **69**, 70, **149**, 150
Auditory Skills Checklist (ASC), 45, **48**, 139–140
AzBio sentences, 17, 43, 99, 115, **116**, 118, 119, 131, 132, 136, 137
"BabyBio" test, 43, 44, 131, 132, **133, 134**, 137
Bamford-Kowal-Bench Quiet test (BKB Quiet), **133**, 136
Bamford-Kowal-Bench Speech-in-Noise test (BKB-SIN), 17, 99, 115, **116**, 131, 132, **133, 134**, 136, 137
Boehm Test of Basic Concepts (BTBC), 70–71, **72**
Bracken School Readiness Assessment (BSRA), 70, 71, **72, 149**, 151
Central Institute for the Deaf (CID) sentences, 115
Central Institute for the Deaf Phonetic Inventory, 148, **148**
Children's Audio-Visual Enhancement Test (CAVET), 167
Children's Home Inventory for Listening Difficulties (CHILD), 46
Children's Realistic Intelligibility of Speech Perception (CRISP), 135, **148**, 149
Client-Oriented Scale of Improvement (COSI), 24–25
Clinical Evaluation of Language Fundamentals (CELF), 62, 66, **67**, 68–69, **68**, 150
Clinical Evaluation of Language Fundamentals-Preschool Edition (CELF-P2), **67**
Cochlear Implant Function Index (CIFI), 25
Cochlear Implant Quality of Life (CIQOL), 25
Comprehensive Assessment of Spoken Language (CASL-2), 68–69, **68**
Comprehensive Test of Phonological Processing (CTOPP), 70, **72**
COnsensus-based Standards for the selection of health status Measurement INstruments (COSMIN), 25
Consonant Nucleus Consonant test (CNC), 17, 43, **116**, 119, **133, 134**, 136
Cottage Acquisition Scales for Listening, Language and Speech-Second Edition (CASSLS), **64**, 65, 66, **67, 69, 148**, 149, 150
Developmental Index of Audition and Listening (DIAL), 46
Dynamic Indicators of Basic Early Literacy Skills assessment (DIBELS), 147, **149**, 151
Early Language Milestone scale (ELM), 46, **48**
Early Speech Perception Test (ESP), 69–70, **69**, 130–131, **133, 134**, 135, **148**, 150
EasyQSMD, 118–119
Expressive One Word Picture Vocabulary Test-4 (EOWPVT-4), 66, **67**, 71
Expressive Vocabulary Test (EVT-3), 66, **67**
Functional Auditory Performance Indicators (FAPI), 45–46, **48**, 150
Functioning After Pediatric Cochlear Implantation (FAPCI) questionnaire, 45, 46, **48**
Glasgow Benefit Inventory (GBI), 25
Glasgow Hearing Aid Benefit Profile (GHABP), 25–26
Goldman-Fristoe Test of Articulation-2 (GFTA-2), 147–148
Goldman-Fristoe Test of Articulation-3 (GFTA-3), **64**, 65
Health Utilities Index (HUI), 26
Hearing Handicap Inventory for Adults (HHIA), 26
Hearing Handicap Inventory for the Elderly (HHI-E), 26
Hearing in Noise Test (HINT), 17, 43, 44, 99, 115, 118
Index of Narrative Complexity, **148**, 150
Infant-Toddler version of Meaningful Auditory Integration Scale (IT-MAIS), 45, **45, 48**
Khan-Lewis Phonological Analysis-Third Edition (KLPA-3), **64**, 65
Lexical Neighborhood Test (LNT), 40, 43, 131, **133, 134**, 136
Lexical Sentence Test, 167
LittlEARS auditory questionnaire, 45, **48**, 139–140
MacArthur-Bates Communicative Development Inventory (CDI), 66, **67, 148**, 150
Meaningful Auditory Integration Scale (MAIS), 45, 46, **48**
Meaningful Use of Speech Sounds (MUSS), 46
Mini-Mental State Examination (MMSE), 162
Minimum Speech Test Battery (MSTB), 15, 16, 17, 18, 22, **23**, 97, 99, 115
Montreal Cognitive Assessment (MoCA), 162–163
Multimodal Lexical Sentence Test for children (MLST-C), 167
Multisyllabic Lexical Neighborhood Test (MLNT), 40, 43, 131, **133, 134**, 136

STUDENTS-HUB.com Uploaded By: tuka abuzneid

New Reynell Developmental Language Scales (RDLS), 66, **67**
Nijmegen Cochlear Implant Questionnaire (NCIQ), 25
Oral and Written Language Scales (OWLS), **68**
PALS-PreK Letter Naming subtest, 62, **72, 149**
Parents' Evaluation of Aural/Oral Performance of Children (PEACH), 46, **48**
Patient-Reported Outcomes Measurement Information System (PROMIS), 25
Peabody Picture Vocabulary Test (PPVT-5), 66, **67**, 150
Pediatric Minimum Speech Test Battery (PMSTB), 40, 41, 42, 43, 45, 47, 97, 99, 129–130, 132, **133, 134**, 136, 137, 139
Pediatric Speech Intelligibility (PSI), 42, 131, **133, 134**, 135
Phonetic-Phonologic Speech Evaluation Record, **148**, 149
Phonetically Balanced Kindergarten (PBK) test, 43
Phonological Awareness Literacy Screening assessments (PALS), 70, **72, 149**, 151
Preschool Language Scale (PLS-5), 66, **67**
Quick Spectral Modulation Detection (QSMD), 118
Receptive One Word Picture Vocabulary Test (ROW-PVT-4), 66, **67**
Reynell Developmental Language Scales (RDLS), 66, **67**
Rosetti Infant Toddler Language Scales (RI-TLS), 64–65, **64**, 66, **67**, 148, **148**, 150
Screening Instrument for Targeting Educational Risk (SIFTER), 71, **73**
SKI-HI Language Development Scale, 66, **68, 148**, 150
Spectral-temporally Modulated Ripple Test (SMRT), 119
Spectro-Temporal Ripple for Investigating Processor Effectiveness (STRIPES), 119
Speech, Spatial, and Qualities questionnaire (SSQ), 24, 98
SRT, **134**
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition, **64**, 65, **68, 69, 148**, 149, 150
Test of Auditory Comprehension of Language-Fourth Edition (TACL-4), **68**, 69
Test of Pragmatic Language, 69
Test of Preschool Early Literacy (TOPEL), 70, **72**
Visual Reinforcement Infant Speech Discrimination (VRISD), 41–42, 132, **134**, 135
Woodcock Johnson Test of Achievement-III (WJTA), 71, **72–73**
Woodcock Reading Mastery Test (WRMT), 71, **72**
The Word Test: Adolescents, **68**
The Word Test: Elementary, **68**
The Word Test-3, 69
Asymmetric hearing loss (AHL), **8**, 96–97
Atretic internal auditory canal, 30, 52
Audiogram, sensation vs. perception, 15, 52
Audiologic evaluation
  adults, 13–14, 111–112
  children, 37–39, 62–73, 125–128
  individual ear assessment, 97
  newborn hearing screening, 38
  postoperative assessment, 111–112, 125–128
  prelingually deafened adolescents and adults, 99
  preoperative, 13–14, 37–39, 62–73
  progress monitoring, 150
Audiometric thresholds
  adults
    postoperative, 111–112, **116**
    preoperative, 14, 28–29
  children, preoperative, 38–39
  cochlear implant "aided" audiometric thresholds, 113
  outcomes and, 28–29, 52
Audiovisual Feature Test, 167
Auditory brainstem implant (ABI), 102
Auditory neuropathy, 30, 52–53
Auditory neuropathy spectrum disorder (ANSD), 30, 38, 52–53
Auditory Perception Test for the Hearing Impaired, Third Edition (APT/HI–3), **69**, 70, **149**, 150
Auditory-related fatigue, 163–166
Auditory-related stress, 164–165
Auditory Skills Checklist (ASC), 45, **48**, 139–140
AzBio sentences, 17, 43, 99, 115, **116**, 118, 119, 131, 132, 136, 137

B

Babbling, infants, 64
"BabyBio" test, 43, 44, 131, 132, **133, 134**, 137
Bacterial meningitis, hearing loss and, 53
BAIs. *See* Bone anchored implants
Bamford-Kowal-Bench Quiet test (BKB Quiet), **133**, 136
Bamford-Kowal-Bench Speech-in-Noise test (BKB-SIN), 17, 99, 115, **116**, 131, 132, **133, 134**, 136, 137
Banakis, R.M., 112
Bennett, R.L., 16
Best-aided condition, 18, 47, 96, 128
Bilateral cochlear implantation, 168–169
Bilingual children, assessment, 71
Biomedical devices
  Class I devices, 2
  Class II devices, 2–3

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Biomedical devices *(continued)*
Class III devices, 3
FDA approval for, 1–10
FDA user fees, 4, **4**
federal regulation of, 1–2, **2**
BKB Quiet. *See* Bamford-Kowal-Bench Quiet test
BKB-SIN. *See* Bamford-Kowal-Bench Speech-in-Noise test
Boehm Test of Basic Concepts (BTBC), 70–71, **72**
Bone anchored implants (BAIs), 97
Bracken School Readiness Assessment (BSRA), 70, 71, **72, 149**, 151
Branchial-oto-renal syndrome, 53
British Cochlear Group, 168
BSRA. *See* Bracken School Readiness Assessment
BTBC. *See* Boehm Test of Basic Concepts

C

Calibration, speech-recognition testing, 19–20
Calibration noise, 21
Candidacy and candidate selection
adults, 13–31
audiologic evaluation, 13–14
expansion of criteria, 93–94, **93**
hearing aid verification, 17–18
medical and surgical evaluation, 27–28
social workers and psychologists in, 26–27
speech-perception metrics, 15–16, **16**
speech-recognition testing, 14–24
subjective evaluation, 24–26
best-aided condition, 18, 47, 96, 128
bilateral implant candidacy, 168–169
children, 37–54
audiologic evaluation, 37–39
evaluation of auditory skills and progress, 44–49
expansion of criteria, 94–95, **95**
with global developmental delay, 100–102, **101**
hearing aid verification, 44–46, 47–49
infants, 95–96
medical and surgical evaluation, 49
social workers and psychologists in, 49
speech-perception metrics, 39
speech-recognition testing, 39–44
word recognition, 43–44
listening effort and fatigue, 163–166
medical and surgical evaluation, 27–28, 49
neurofibromatosis type 2 (NF2), 102
nontraditional candidates, 91–103
prelingually deafened adolescents and adults, 98–100, **100**
social workers and psychologists in, 26–27, 49
speech-language pathologists and, 47, 61–74
Caraway, Theresa, 141
Carhart, Raymond, 15
CASL-2. *See* Comprehensive Assessment of Spoken Language
CASSLS. *See* Cottage Acquisition Scales for Listening, Language and Speech-Second Edition
CAVET. *See* Children's Audio-Visual Enhancement Test
CDI. *See* Communicative Development Inventory
CELF. *See* Clinical Evaluation of Language Fundamentals
CELF-P2. *See* Clinical Evaluation of Language Fundamentals-Preschool Edition
Center of Devices and Radiological Health (CDRH), 1–2, **2**
Centers for Medicare/Medicaid Services (CMS)
adult implant criteria, 6, **8**, 14, 15, 17
contraindications to cochlear implants, 10
Central Institute for the Deaf (CID) sentences, 115
Central Institute for the Deaf Phonetic Inventory, 148, **148**
Charcot-Marie-Tooth disease, 30
CHARGE syndrome, 53
Children
assessment of, 39–44, 61–74, 171
audiologic evaluation, 37–39
bilateral cochlear implantation, 168–169
bilingual children, 171
candidate selection, 37–54
audiologic evaluation, 37–39
audiometric thresholds, 38–39
children with global developmental delay, 100–102, **101**
evaluation of auditory skills and progress, 44–49
expansion of criteria, 94–95, **95**
hearing aid verification, 44–46, 47–49
infants, 95–96
medical and surgical evaluation, 49
social workers and psychologists in, 49
speech-language pathologist and, 47, 61–74
speech-perception metrics, 39
speech recognition criteria, **9**, 10
speech-recognition testing, 39–44
word recognition, 43–44
labeled indications, **9**, 10
listening effort, 165–166
postoperative assessment, 125–141, 167
audiologic evaluation, 125–128
social worker and psychologist in, 139
speech-language pathologists and, 145–156
speech recognition testing, 128–139
postoperative medical management, 139–140
See also Infants

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Children's Audio-Visual Enhancement Test (CAVET), 167
Children's Home Inventory for Listening Difficulties (CHILD), 46
Children's Realistic Intelligibility of Speech Perception (CRISP), 135, **148**, 149
Chorda tympani, 78
Chromosome-related deafness, 53
CIFI. *See* Cochlear Implant Function Index
CIQOL. *See* Cochlear Implant Quality of Life
Clark, J., 15
Class I medical devices, 2
Class II medical devices, 2–3
Class III medical devices, 3
Client-Oriented Scale of Improvement (COSI), 24–25
Clinical Evaluation of Language Fundamentals (CELF), 62, 66, **67**, 68–69, **68**, 150
Clinical Evaluation of Language Fundamentals-Preschool Edition (CELF-P2), **67**
Closed-set tests, 41, 42, 130–131, 135–136
CMS. *See* Centers for Medicare/Medicaid Services
CNC. *See* Consonant Nucleus Consonant test
CND. *See* Cochlear nerve deficiency
Cochlea
  anatomy relevant to implantation, 77–82
  anomalies and outcomes, 29–31, 52
  orientation of within temporal bone, 80
  surgical approaches, 77–80, **79, 81**, 82
Cochlear Americas
  adult implant criteria, 6, 14, 15, 17, 18, 94
  EAS systems, 6, 10
  Hybrid-L24, **7**, 18
  preoperative imaging, 50
  Profile and Profile Plus, 6, **7, 9**, 10
Cochlear anomalies, outcomes and, 29–31, 52
Cochlear duct, 80, **81**
Cochlear implant devices
  classes, 2–3
  device modifications requiring PMA approval, 4–5
  FDA approval for, 1–10
  FDA funding for, 3–4, **4**
  labeled indications, 6, **7–9**, 10
  off-label usage, 6
  user fees, 4, **4**
Cochlear Implant Function Index (CIFI), 25
Cochlear Implant Quality of Life (CIQOL), 25
Cochlear implant surgeon, 27, 49, 78, 120
Cochlear implant surgery, 31, 77–88
  approaches to cochlea, 77–80, **79, 81**, 82
  clinical implant placement, 82–84, **83**
  customized surgical techniques, 85–86
  electrophysiological monitoring during surgery, 86
  planning, 85–86
  postoperative correction, 86–88
  postoperative management, 120–121, 139–140
  preoperative imaging, 85–86
  problems and suboptimal events, 82–84, **83**
    clinical implications of, 84–88
    extracochlear electrodes, 84, 86–87
    lateralization of precurved electrodes, 83–84, **83**
    postoperative correction, 86–88
    scalar translocation, 82–83, **83**
    tip fold-over, 82, **83**
  risks to infants, 96
Cochlear implantation
  adults
    neurofibromatosis type 2 (NF2), 102
    outcomes, 159–170
    postoperative assessment, 111–121
    prelingually deafened adults, 98–100, **100**
    selection, 13–31
  age and candidacy, 28
  aging population and, 161–162
  anatomy relevant to, 77–82
  barriers to, 91–93
  bilateral implants, 168–169
  candidacy. *See* Candidacy and candidate selection
  children
    with global developmental delay, 100–102, **101**
    outcomes, 159–170
    postoperative assessment, 125–141
    selection, 37–54
  contraindications, 10
  electric and acoustic stimulation (EAS) systems, 6, 10
  medical and surgical evaluation, 27–28
  medical issues
    immunizations prior, 49
    preoperative evaluation, 49–50
    preoperative imaging, 50
  nontraditional candidates for, 91–103
  outcomes. *See* Outcomes
  postoperative assessment
    of adults, 111–121
    of children, 125–141
    speech-language pathologists and, 145–156
  for prelingually deafened adolescents and adults, 98–100, **100**
  referral for, 92–93
  social workers and psychologists in assessment, 26–27
  speech-language pathologist and, 47, 61–74, 145–156
  speech recognition criteria, 6, **7–9**, 10
  surgery. *See* Cochlear implant surgery
  underutilization of, 92
Cochlear nerve deficiency (CND), 52
Cochleostomy, 80

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Cognitive decline, hearing loss and, 160–163, **161, 162**
Common cavity, 52
Communicative Development Inventory (CDI), 66, **67, 148**, 150
Comprehensive Assessment of Spoken Language (CASL–2), 68–69, **68**
Comprehensive Test of Phonological Processing (CTOPP), 70, **72**
Cones, H., 165
COnsensus-based Standards for the selection of health status Measurement INstruments (COSMIN), 25
Consonant Nucleus Consonant test (CNC), 17, 43, **116**, 119, **133, 134**, 136
Contralateral routing of sound (CROS) hearing aid systems, 97
Cosetti, M., 96
COSI. *See* Client-Oriented Scale of Improvement
COSMIN. *See* COnsensus-based Standards for the selection of health status Measurement INstruments
Cottage Acquisition Scales for Listening, Language and Speech-Second Edition (CASSLS), **64**, 65, 66, **67, 69, 148**, 149, 150
CRISP. *See* Children's Realistic Intelligibility of Speech Perception
Criterion-referenced assessments, 62, 65, 66, 70, 71, 147, 150
CROS. *See* Contralateral routing of sound (CROS) hearing aid systems
Cross-modal plasticity, 167
CTOPP. *See* Comprehensive Test of Phonological Processing

D

Dementia, hearing loss and, 160–163, **161, 162**
Demographics, aging population, 160
Depression, 27, 120
Developmental delay, candidacy of children with, 100–102, **101**
Developmental Index of Audition and Listening (DIAL), 46
DIBELS. *See* Dynamic Indicators of Basic Early Literacy Skills assessment
Down syndrome, hearing loss and, 53
Dynamic Indicators of Basic Early Literacy Skills assessment (DIBELS), 147, **149**, 151

E

EAC. *See* External auditory canal
Early Language Milestone scale (ELM), 46, **48**
Early Speech Perception Test (ESP), 69–70, **69**, 130–131, **133**, **134**, 135, **148**, 150
EasyQSMD, 118–119
EBP. *See* Evidence-based practice
ECochG. *See* Electrocochleography
Electric and acoustic stimulation (EAS) systems, 6, 10
Electrocochleography (ECochG), 86
Electrode arrays, 82
Electrophysiological monitoring, during surgery, 86
ELM. *See* Early Language Milestone scale
Enlarged vestibular aqueduct, 29, 52
EOWPVT-R. *See* Expressive One Word Picture Vocabulary Test
Erber, N., 152
ESP. *See* Early Speech Perception Test
Evidence-based practice (EBP), 24
Expressive One Word Picture Vocabulary Test-4 (EOWPVT-4), 66, **67**, 71
Expressive Vocabulary Test (EVT-3), 66, **67**
Extended round window approach, 80
External auditory canal (EAC), 78

F

"Facial halves," 80
Facial recess, 78, **79**, 80
FAPCI questionnaire. *See* Functioning After Pediatric Cochlear Implantation (FAPCI) questionnaire
FAPI. *See* Functional Auditory Performance Indicators
FDA. *See* Food and Drug Administration
Federal Food, Drug, and Cosmetic Act (FD&C Act) (1938), 2
Fidell, S., 16
Firszt, J.B., 97
Flexible team boundaries, 141
Food and Drug Administration (FDA), mission of, 1
Food and Drug Administration (FDA) approval
  cochlear implant criteria, 6, **7–9**, 10
  of cochlear implantation devices, 1–10, 37
  device modifications requiring PMA approval, 4–5
  existing devices, 1
  fees for medical devices, 4, **4**
  investigational device exemption (IDE), 5
  labeled indications, 5–6, **7–9**, 10, 37
  least burdensome approach, 4–5
  new devices, 3
  off-label usage, 6
  premarket approval (PMA), 2, 3, 4, **4**
  real-time supplement, 5
  review process, 3–4
Form effect, 147
Friedreich's ataxia, 30

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Functional Auditory Performance Indicators (FAPI), 45–46, **48**, 150
Functional neuroimaging, 167–168
Functioning After Pediatric Cochlear Implantation (FAPCI) questionnaire, 45, 46, **48**

G

Galvanic skin response, listening effort and, 164, 165
Gantz, J., 29
GBI. *See* Glasgow Benefit Inventory
Generalized linear model (GLM), 84–85, **85**
GFTA-2. *See* Goldman-Fristoe Test of Articulation-2
GFTA-3. *See* Goldman-Fristoe Test of Articulation-3
GHABP. *See* Glasgow Hearing Aid Benefit Profile
Glasgow Benefit Inventory (GBI), 25
Glasgow Hearing Aid Benefit Profile (GHABP), 25–26
GLM. *See* Generalized linear model
GN Otometrics, 167
Goldman-Fristoe Test of Articulation-2 (GFTA-2), 147–148
Goldman-Fristoe Test of Articulation-3 (GFTA-3), **64**, 65
Goman, A.M., 91, 160
Gordon, K., 97
"Guidelines for the Audiologic Management of Adult Hearing Impairment" (American Academy of Audiology), 17

H

Haplin, C., 28
Hardy, Mary, 80, 82
Health insurance, 92, 121
Health Utilities Index (HUI), 26
Hearing aids
  contralateral routing of sound (CROS) hearing aid systems, 97
  verification, 17–18, 44–49
  wear time and postoperative outcome, 51
Hearing Handicap Inventory for Adults (HHIA), 26
Hearing Handicap Inventory for the Elderly (HHI-E), 26
Hearing in Noise Test (HINT), 17, 43, 44, 99, 115, 118
Hearing loss
  asymmetric hearing loss, **8**, 96–97
  chromosome-related deafness, 53
  dementia and, 160–163, **161, 162**
  listening effort, 163–166
  meningitis-associated, 30–31, 53
  prelingually deafened adolescents and adults, 98–100, **100**
  presbycusis, 160
  single-sided deafness (SSD), 6, **8**, 97
  syndromic hearing loss, 30, 53
  unilateral hearing loss, 97–98
Hearing status assessment. *See* Audiologic evaluation
Heart rate variability (HRV), listening effort and, 164–165
Hebert, L.E., 160
Heydebrand, G., 163
HHI-E. *See* Hearing Handicap Inventory for the Elderly
HHIA. *See* Hearing Handicap Inventory for Adults
HINT. *See* Hearing in Noise Test
Holder, J.J., 86–87
Horizontal semicircular canal, 78, **79**
House, William, 78
HRV. *See* Heart rate variability
HUI. *See* Health Utilities Index

I

IDE. *See* Investigational device exemption
Imaging
  postoperative, 88, 167–168
  preoperative, 50, 85–86
  structural neuroimaging, 167–168
Immunizations, prior to cochlear implantation, 49
Index of Narrative Complexity, **148**, 150
Infant-Toddler version of Meaningful Auditory Integration Scale (IT-MAIS), 45, **45, 48**
Infants
  babbling, 64
  candidacy for implants, 95–96
  "facial halves," 80
  language assessment, 66
  speech development in, 39
  speech production, 63–64
  speech recognition testing, 41–42
  surgical risks of implantation in, 96
Input calibration, speech-recognition testing, 20
Insurance, 121
Investigational device exemption (IDE), 5
IT-MAIS. *See* Infant-Toddler version of Meaningful Auditory Integration Scale

K

Khan-Lewis Phonological Analysis-Third Edition (KLPA-3), **64**, 65
Koerner's septum, 78

L

Language assessment, 65–66, **67–68**, 68–69, 150
Language exposure, 54

STUDENTS-HUB.com Uploaded By: tuka abuzneid

Language learning, postimplantation, 151–155
Lateral wall electrodes, 82
Lateralization of precurved electrodes, 83–84, **83**
Leigh, J.R., 95
Lexical density, 43
Lexical neighbor, 43, 136
Lexical Neighborhood Test (LNT), 40, 43, 131, **133, 134**, 136
Lexical Sentence Test, 167
Lin, E.R., 91
Linear weighting, 16*n*1, 129*n*1
Listening effort, 163–166
Litovsky, Ruth, 135
LittlEARS auditory questionnaire, 45, **48**, 139–140
LNT. *See* Lexical Neighborhood Test

M

MacArthur-Bates Communicative Development Inventory (CDI), 66, **67, 148**, 150
Mackersie, C.L., 111, 165
Madell, J.R., 138
MAIS. *See* Meaningful Auditory Integration Scale
Maladaptive plasticity, 168
Marginal round window cochleostomy, 80
Mastoid anatomy, 78, **79**
Mastoidectomy, 77–78
MDRs. *See* Medical Device Reports
Meaningful Auditory Integration Scale (MAIS), 45, 46, **48**
Meaningful Use of Speech Sounds (MUSS), 46
MED-EL
  adult implant criteria, 6, **7–9**, 10, 14, 15, 17, 94
  EAS systems, 6, **8**, 10, 17, 18
  pediatric implant criteria, 38
  preoperative imaging, 50, 85–86
  SSD, 18, 97
  Synchrony and Synchrony 2, **7, 8, 9**
  Synchrony and Synchrony 2 EAS, **8**, 10
Medical Device Reports (MDRs), 3
Medical Device User Fee and Modernization Act (MDUFMA) (2002), 4
Medical Devices Amendments (1976), 2
Medical evaluation, to determine candidacy, 27–28, 49–50
Medicare, 120
Medicare/Medicaid Services. *See* Centers for Medicare/Medicaid Services
Meningitis, hearing loss associated with, 30–31, 53
Mini-Mental State Examination (MMSE), 162
Minimum Speech Test Battery (MSTB), 15, 16, 17, 18, 22, **23**, 97, 99, 115
MLNT. *See* Multisyllabic Lexical Neighborhood Test
MLST-C. *See* Multimodal Lexical Sentence Test for children
MMSE. *See* Mini-Mental State Examination
MoCA. *See* Montreal Cognitive Assessment
Mondini dysplasia, 29, 52
Monitored live voice (MLV), 15, **16**, 40, 115, 128–129
Monosyllabic word criterion, 10
Montreal Cognitive Assessment (MoCA), 162–163
MSTB. *See* Minimum Speech Test Battery
Multimodal Lexical Sentence Test for children (MLST-C), 167
Multisyllabic Lexical Neighborhood Test (MLNT), 40, 43, 131, **133, 134**, 136
MUSS. *See* Meaningful Use of Speech Sounds

N

NCIQ. *See* Nijmegen Cochlear Implant Questionnaire
Neighborhood Activation Model, 43
Neural anomalies, outcomes and, 29–31
Neurofibromatosis type 2 (NF2), cochlear implantation and, 102
Neuropathy, of auditory nerve, 30, 38, 52–53
New Reynell Developmental Language Scales (RDLS), 66, **67**
Newborn hearing screening, 38
Nijmegen Cochlear Implant Questionnaire (NCIQ), 25
Noise, speech recognition in, 43–44, 131–132, **133–134**, 135, 137
Non-English speaking recipients, assessment of, 118–119
Nonexempt Class I devices, 2
Norm-referenced assessments, 62, 66, 71, 146–147
Nucleus Hybrid-L24, **7**, 17

O

OAEs. *See* Otoacoutic emissions
"Off-Label and Investigational Use of Marketed Drugs, Biologics, and Medical Devices" (FDA), 6
Off-label usage, 6
Office of Compliance, 3
Office of Device Evaluation, 3
Office of Ophthalmic, Anesthesia, Respiratory, ENT, and Dental Devices, 3
Office of Product Evaluation and Quality (OPEQ), **2**, 3
Office of Science and Engineering Laboratories (OSEL), **2**, 3
Office of Surveillance and Biometrics, 3
Open-set sentence recognition, 43, 136–137
Open-set word recognition, 136

STUDENTS-HUB.com Uploaded By: tuka abuzneid

OPEQ. *See* Office of Product Evaluation and Quality
Oral and Written Language Scales (OWLS), **68**
OSEL. *See* Office of Science and Engineering Laboratories
Otoacoutic emissions (OAEs), 14, 38
Otologist, 49–50, 139–140
Otosclerosis, 31
Outcomes, 28–31, 50–54, 159–170
  age and, 28, 50–51
  audiometric thresholds and, 28–29, 52
  cochlear anomalies and, 29–31, 52
  cognitive decline risk, 160–163, **161**, **162**
  duration of deafness and, 29
  integrity of cochlear and neural structures and, 29–31, 52–53
  listening effort and fatigue, 163–166
  multisensory assessment, 166–167
  neurofibromatosis type 2 (NF2) and, 102
  preoperative speech perception and, 29
  speech/language therapy and, 51–52
  wear time and, 51
Output calibration, speech-recognition testing, 20
OWLS. *See* Oral and Written Language Scales

P

PALS. *See* Phonological Awareness Literacy Screening assessments
PALS-PreK Letter Naming subtest, 62, **72, 149**
Parents' Evaluation of Aural/Oral Performance of Children (PEACH), 46, **48**
Parkinson, W.S., 29
Patient-Reported Outcomes Measurement Information System (PROMIS), 25
PBK test. *See* Phonetically Balanced Kindergarten (PBK) test
Peabody Picture Vocabulary Test (PPVT-5), 66, **67**, 150
PEACH. *See* Parents' Evaluation of Aural/Oral Performance of Children
Pearsons, K.S., 16
Pediatric Minimum Speech Test Battery (PMSTB), 40, 41, 42, 43, 45, 47, 97, 99, 129–130, 132, **133, 134**, 136, 137, 138
Pediatric Speech Intelligibility (PSI), 42, 131, **133, 134**, 135
PediatricAzBio, 44, 137
Pendred syndrome, 53
Perception, sensation vs., 14–15, 52
Perimodiolar electrodes, 82
Phonetic-Phonologic Speech Evaluation Record, **148**, 149
Phonetically Balanced Kindergarten (PBK) test, 43
Phonological Awareness Literacy Screening assessments (PALS), 70, **72, 149**, 151
Plasticity, 167–168
PLS-5. *See* Preschool Language Scale
PMSTB. *See* Pediatric Minimum Speech Test Battery
Pneumonococcal vaccination, prior to cochlear implantation, 49
Pneumovax 23, 49
Population demographics, aging population, 160
Postoperative assessment
  adults, 111–121
    audiologic evaluation, 111–114
    non-English speaking recipients, 118–119
    social worker and/or psychologist in, 120
    speech-perception metrics, 114–115, **116–117**
    speech recognition testing, 114–118
    subjective evaluation, 119
  children, 125–141
    audiologic evaluation, 125–128
    social worker and psychologist in, 139
    speech-language pathologist and, 145–156
    speech-perception metrics, 130–131
    speech recognition testing, 128–139, 167
    timeline for, **146**
  postoperative progress monitoring, 145–156
  timeline for, **146**
Postoperative outcomes. *See* Outcomes
PPVT-5. *See* Peabody Picture Vocabulary Test
Practice effect, 147
Precurved electrode arrays, 82, 83–84, **83**, 85
Prelingually deafened adolescents and adults, cochlear implants for, 98–100, **100**
Premarket approval (PMA), 2, 3, 4, **4**
Presbycusis, 160
Preschool Language Scale (PLS-5), 66, **67**
Presentation level, speech recognition testing, 16, 40, **41**
Prevnar 13, 49
"Priority protocol," 132, **133–134**
Probe-microphone measurements, 18
Proficiency, 63
Progress monitoring instruments, 145–156, **147–149**
PROMIS. *See* Patient-Reported Outcomes Measurement Information System
PSI. *See* Pediatric Speech Intelligibility
Psychologists
  candidate selection, 26–27, 49
  postoperative assessment and management, 120, 139
Psychosocial symptoms, 27
Pupillometry, listening effort and, 164

Q

Quick Spectral Modulation Detection (QSMD), 118

STUDENTS-HUB.com Uploaded By: tuka abuzneid

R

R-Space™ system, 169, **169**
RDLS. *See* Reynell Developmental Language Scales
Real-ear-to-coupler-difference (RECD), 47, 112, 128
Receptive One Word Picture Vocabulary Test (ROW-PVT-4), 66, **67**
Recorded materials, for speech recognition testing, 15, 39–40, 128–129
Refsum disease, 53
Remote microphone systems, 97
Reynell Developmental Language Scales (RDLS), 66, **67**
RI-TLS. *See* Rosetti Infant Toddler Language Scales
Roeser, R., 15
Roland, J.T., 96
Rosetti Infant Toddler Language Scales (RI-TLS), 64–65, **64**, 66, **67**, 148, **148**, 150
Round window (RW), 78–80, **79**
ROW-PVT-4. *See* Receptive One Word Picture Vocabulary Test
Rubinstein, J.T., 29

S

Scala media (SM), 79
Scala tympani (ST), 79
Scala vestibuli (SV), 79
Scalar translocation, 82–83, **83**
Screening Instrument for Targeting Educational Risk (SIFTER), 71, **73**
Sensation, perception vs., 14–15, 52
Sentence recognition, in children, 136–137
SIFTER. *See* Screening Instrument for Targeting Educational Risk
Sigmoid sinus, 78
Single-sided deafness (SSD), labeled indicators, 6, **8**, 97
SKI-HI Language Development Scale, 66, **68**, **148**, 150
Skin-conductance, listening effort and, 164, 165
Skinner, M.W., 113, 125–126
SLPs. *See* Speech-language pathologists
SM. *See* Scala media
SMRT. *See* Spectral-temporally Modulated Ripple Test
Social workers
  candidate selection, 26–27, 49
  postoperative assessment and management, 120, 139
Socrates, 85
Sound-field thresholds, 126
Special populations, assessment of, 71, 73
Spectral-temporally Modulated Ripple Test (SMRT), 119
Spectro-Temporal Ripple for Investigating Processor Effectiveness (STRIPES), 119
Speech development, in infants, 39
Speech-language pathologists (SLPs)
  cochlear implant candidate selection, 47, 61–74
  postoperative assessment of children, 145–156
  preoperative assessments of children, 61–74
Speech/language therapy
  following hearing aid therapy, 74
  outcomes and, 51–52
  postimplantation therapy, 151–153
  preimplantation therapy, 73–74
Speech-perception metrics
  postoperative assessment, 114–115, **116–117**, 130–131
  preoperative, 15–16, **16**, 39
Speech production, assessment, 63–64, **64**
Speech recognition
  criteria
    adults, 6, **7–8**, 10
    children, **9**, 10
  in noise, 43–44, 131–132, **133–134**, 135
  performance, 17
Speech recognition testing, 14–24, 166–167
  adult assessment, 17–22
  of children, 39–44
  hearing aid verification, 17–18, 44–46, 47–49
  metrics, 15–16, **16**, 39, 114–115, **116–117**, 130–131
  Minimum Speech Test Battery (MSTB), 15, 16, 18, 22, **23**, 97, 99, 115
  monitored live voice (MLV), 15, **16**, 40, 115, 128–129
  monosyllabic word criteria, 17
  multiple estimates of, 40–41
  in noise, 43–44, 131–132, **133–134**, 135
  for non-English speaking recipients, 118–119
  postoperative
    adults, 114–118
    children, 128–139
  presentation level, 16, 40, **41**
  recorded materials, 15, 39–40, 128–129
  sensation vs. perception, 14–15, 52
  setup and calibration, 19–22, **19–22**
  test materials, 17
  testing conditions, 18
  time allotted, 22–24, **23**
Speech, Spatial, and Qualities questionnaire (SSQ), 24, 98
SPICE curriculum, 153
SRT, **134**
SSD. *See* Single-sided deafness

STUDENTS-HUB.com Uploaded By: tuka abuzneid

SSQ. *See* Speech, Spatial, and Qualities questionnaire
ST. *See* Scala tympani
St. Gabriel's Curriculum for the Development of Audition, Language, Speech, and Cognition, **64**, 65, **68, 69, 148**, 149, 150
Standardized assessments, 61–62
Stern, R.E., 92
Straight electrode arrays, 82, 84, 85
STRIPES. *See* Spectro-Temporal Ripple for Investigating Processor Effectiveness
Structural neuroimaging, 167–168
Substantial equivalence, 2, 3
Surgeon. *See* Cochlear implant surgeon
Surgery. *See* Cochlear implant surgery
Surgical evaluation, to determine candidacy, 27–28, 49
SV. *See* Scala vestibuli
Syndromic hearing loss, 30, 53

T

Tegmen, 78
Test of Auditory Comprehension of Language-Fourth Edition (TACL-4), **68**, 69
Test of Pragmatic Language, 69
Test of Preschool Early Literacy (TOPEL), 70, **72**
Tinnitus, 98
Tip fold-over, 82, **83**
Total Product Lifecycle approach, 3
Trisomy 21, hearing loss and, 53
21st Century Cures Act (2016), 2
Tyler, R.S., 29
Tympanometry, postoperative assessment, **116**, 127

U

Uhler, K., 40
Unilateral hearing loss, 97–98
See also Single-sided deafness
Usher syndrome, 53

V

van Dijkhuizen, J.N., 99
Vestibular schwannomas, 102
Visual reinforcement audiometry (VRA), 130
Visual Reinforcement Infant Speech Discrimination (VRISD), 41–42, 132, **134**, 135

W

Waardeburg syndrome, 53
William House Cochlear Implant Study Group, 168
Woodcock Johnson Test of Achievement-III (WJTA), 71, **72–73**
Woodcock Reading Mastery Test (WRMT), 71
Word frequency, 43
Word recognition, in children, 42–43, 44, 136
Word segmentation, 39
The Word Test: Adolescents, **68**
The Word Test: Elementary, **68**
The Word Test-3, 69

STUDENTS-HUB.com Uploaded By: tuka abuzneid

STUDENTS-HUB.com Uploaded By: tuka abuzneid