Pediatric Amplification: Enhancing Auditory Access

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Preface

The clinical processes related to providing amplification for infants and children have changed rapidly in recent years. The idea that children could be identified with hearing loss at birth and that hearing aids could be provided within the first few months of life seemed unfathomable several decades ago. In the 21st century, we have a new generation of children with hearing loss who have the opportunity to be fit with hearing aids at very young ages and receive quality, family-centered early intervention. The field of pediatric audiology has responded to this new opportunity by developing clinical processes and protocols so that the full potential of these opportunities can be realized. The changes in the population of children who are hard of hearing and the clinical practices that are needed to support them were a major contributing factor to the decision to write this book.

There are a number of excellent book chapters and review articles that cover the topic of providing amplification for infants and children, many of which have been cited in this book. These other resources inspired our efforts to develop an entire textbook that follows not only the clinical processes of providing amplification for infants and children, but also the screening and diagnostic assessment that leads to a diagnosis of hearing loss. An expanded discussion of the use of outcome measure to monitor auditory development and speech perception was included to describe the important steps that occur after the hearing aids are fitted. The inclusion of a chapter on outcome validation led to the inclusion of a specific chapter on assessing children who are under consideration for cochlear implant candidacy. Each component of this textbook seemed to lead to the inclusion of another facet of the pediatric amplification process.

The potential danger in the approach of writing a textbook in this way is that the book could end up being a collection of tangential concepts. Fortunately, at the same time that we were thinking of writing this book, we were also privileged enough to be co-investigators in the longitudinal, multi-center Outcomes of Children with Hearing Loss (OCHL) and Outcomes of School-Age Children who are Hard of Hearing studies. As described by our esteemed colleague, Dr. Mary Pat Moeller, in the Foreword, the scientific framework of those studies served as a natural organizational structure for describing the processes that are related to providing amplification for children. The main goal of providing amplification for children who are hard of hearing is to enhance their auditory access. Over time, we strive to improve their cumulative auditory experience. The theoretical model of cumulative auditory experience not only helped us learn about the areas of risk and resilience experienced by children who are born with hearing loss and use hearing aids, but also provides clinical guidance on the goals and objectives that should guide an evidence-based approach to providing amplification for children.

As will be obvious from the first chapter, these concepts about maximizing auditory experience for children with hearing loss are not novel. These themes are apparent in the pioneering research of Julia Davis and her colleagues at the University of Iowa in the 1970s and 1980s, which was continued by Patricia Stelmachowicz at Boys Town National Research Hospital in the 1990s and 2000s. What is new is our ability to apply these ideas to children at younger ages. Early identification and intervention of hearing loss has the potential for greater impact on language and academic achievement than ever before. We hope that this text provides a comprehensive resource for professionals who serve children who are hard of hearing and their families and caregivers.

Foreword

Pediatric amplification practices have evolved in a myriad of ways in an era of early identification and advancing hearing technologies. Practicing audiologists serve the youngest of infants and their families, adapt their strategies to meet the children's changing needs as they grow, monitor children's outcomes, and maintain currency regarding the increasing array of technologies that may be applied across children's developmental course to adulthood. All the while, practitioners strive to incorporate the best scientific evidence while individualizing their procedures to the needs of their patients and families. In reality, this can be a tall order. It is challenging to stay current with the burgeoning research literature and the moving target that represents current technology. *Pediatric Amplification: Enhancing Auditory Access* addresses this reality by providing a comprehensive and practical management guide that is elegantly interwoven with theory and supporting research evidence. This volume translates the science into a comprehensive set of resources that readers will find indispensable in their quest to provide evidence-based practice.

The text begins by introducing the reader to the theory of cumulative auditory access, and this foundational theoretical model is expertly integrated throughout subsequent chapters. The authors' clear elucidation of the theory clarifies the essential role that appropriately fit amplification plays in providing children with robust access to linguistic input and developmental opportunities. This theory is immediately backed up with current evidence drawn from an National Institute for Deafness and Other Communication Disorders-funded longitudinal study, *Outcomes of Children with Hearing Loss.* As a co-principal investigator of this project, I had the honor and pleasure of working side by side with the authors of this text, Ryan W. McCreery and Elizabeth A. Walker. Their contributions to the project were immense, and their research and clinical experiences are now expertly distilled in the pages that follow.

The introductory chapter sets the stage for remainder of the book. I expected to learn from reading this work, but I was also inspired by it. Concepts tackled in the introduction will pique interest and motivate readers to want to know the specific research findings and their implications for positively impacting children's outcomes. In the first chapter and throughout the book, concepts are organized in terms of malleable and nonmalleable influential factors—those factors we can directly impact in practice, and those that we may not be able to address head on, but need to consider and influence in indirect ways. This is a useful dichotomy that will provoke readers to think about novel ways to approach old problems.

The subsequent chapters provide comprehensive coverage of the essential topics related to pediatric amplification, including diagnosis of hearing loss, selecting amplification, and verifying hearing aid fittings for children. An entire chapter is devoted to the topic of hearing aid orientation and strategies for enhancing hearing aid use. Given recent evidence demonstrating the challenges of hearing aid use for some infants and young children, readers will find a rich set of evidence and resources to guide their work with families. This is paired with a chapter on evidence and techniques for monitoring auditory outcomes in children, which is essential for determining if hearing aid fittings are bringing about expected outcomes. Also provided are essential strategies for identifying children in need of additional or modified supports at the earliest possible ages. Meredith Spratford joins the primary authors in a discussion of the use of remote-microphone and connective device technologies to enhance cumulative auditory experience. Particularly innovative is the exploration of this topic in a developmental framework, considering the varied applications of technologies from infancy in the home through the young adulthood, when students access a range of electronic media sources. Another chapter is devoted to unique adaptations for special

populations. The text concludes with case studies, which allow for application of the concepts presented throughout the book in way that guides both the "art" and the "science" of pediatric practice.

This volume is a treasure trove of resources for pediatric audiologists. The authors uniquely blend developmental theory with current evidence, resulting in considerable motivation and support for the clinical practice recommendations provided. This text will convince readers of the critical importance of best practices and why they matter for children's outcomes. It is a must read for those engaged in pediatric audiology in any arena. It will become a valued resource that guides the effort to promote optimal developmental outcomes for children in this promising era of early service provision.

—Mary Pat Moeller, PhD

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An Introduction to Cumulative Auditory Experience

Ryan W. McCreery and Elizabeth A. Walker

INTRODUCTION

The recent implementation of universal newborn hearing screening and early diagnosis and intervention in many countries around the world creates an opportunity for a brighter future for children who are deaf or hard of hearing. Hearing loss is the most frequently occurring congenital condition identified at birth. Decades of evidence have documented the negative developmental consequences that occur when a child's access to sound is limited. Fortunately, hearing technologies and family-centered early intervention have shifted the landscape of service provision for children who are deaf or hard of hearing, leading us to expect that language delays can be minimized or prevented altogether. In the following chapter, we will provide an overview of the concept of *cumulative auditory experience*: how hearing loss affects development by limiting access to sound over time. We will discuss the following topics in detail:

- The effects of early identification and intervention of hearing loss on developmental outcomes over time
- The role of hearing aids in enhancing auditory experience in children
- Clinical strategies for maximizing auditory experience in children with hearing loss

Our goal in this introductory chapter is to provide a theoretical foundation for the model that will serve as the basis for the rest of the text.

THE EFFECTS OF HEARING LOSS ON DEVELOPMENT IN CHILDREN

Congenital or prelingual hearing loss affects development by reducing access to acoustic cues needed to fuel the development of speech and language. Language development is driven by perceptual experiences and interactions with other people that begin even before a child is born.

Studies have shown within a few hours of birth, newborns show clear preferences for their mother's voice over others (DeCasper & Fifer, 1980; Mehler, Bertoncini, Barrière, & Jassik-Gerschenfeld, 1978), suggesting that formative auditory experiences begin in the womb. Cross-linguistic studies have indicated that young infants' preferences for sounds in their primary language over speech sounds from other languages emerge within the first few months of life (Werker & Tees, 1984). This process of increasing sensitivity for the acoustic cues in their native language provides infants with early tools to learn new words and to develop a system of language (Werker & Yeung, 2005). Learning to communicate is driven by language input from the child's environment and occurs as soon as the child can hear prenatally. For the child who is hard of hearing, this early auditory experience may be reduced or eliminated.

In children who have hearing loss at birth or acquire it early in the process of developing language, language learning can be significantly interrupted, though the prospects for children who are deaf or hard of hearing have improved immensely over the last century. Early descriptions of deafness in children focused primarily on children with severe or profound hearing loss and limited residual hearing, which was equated to sensory deprivation (Myklebust, 1960). In those early years, the lack of early identification and intervention programs meant that children who were deaf or hard of hearing faced substantial delays in communication development, which often cascaded into academic and social problems during school age. Given the limited residual hearing and auditory access associated with profound hearing loss, such significant language development problems were not surprising.

Perhaps more surprising was the fact that nearly any amount of hearing loss was found to impact the emergence of speech and language abilities. Children with milder degrees of hearing loss were not as well studied as their peers with severe and profound degrees of hearing loss, but even early investigations found that milder degrees of hearing loss could be quite disruptive to development. For example, one of the first investigations of vocabulary and reading ability in a cohort of children with hearing losses ranging from mild to profound found that children with hearing loss experienced delays in language and reading abilities compared to peers with normal hearing, even for mild or moderate losses (Hood, 1949). This observation ran against the prediction that the amount of disruption in communication development might be easily predicted by the child's degree of hearing loss. Further pioneering work by Julia Davis and her colleagues helped to reveal the developmental challenges faced by children with mild or moderate hearing losses. In one of many studies authored by Davis, Elfenbein, Schum, and Bentler (1986), Davis challenged the idea that the developmental effects of hearing loss were entirely predictable based on the child's degree of hearing loss. As Davis wrote:

> The data indicate that it is not possible to predict hearing-impaired children's language or educational performance on the basis of degree of hearing loss alone, whether the measure used is a pure-tone average or one of speech reception and/or recognition. Therefore, the assumption that the greater the hearing loss the more severe the language and educational deficits is not supported by these data . . . (p. 51)

Davis had identified that while the child's degree of hearing loss was one potential factor in predicting developmental outcomes, there were many other aspects related to children and their environment at play that could be pivotal in helping to guide intervention. The prevailing assumption at the time, which was that children with the most significant degrees of hearing loss might be at the greatest risk, led to an intense focus on developing interventions for children with the greatest degrees of hearing loss, including cochlear implants. Less emphasis was placed on children with mild and moderate degrees of hearing loss who wore hearing aids, based on the assumption that milder degrees of loss would not lead to significant problems in communication development. This focus prompted Julia Davis to refer to children with mild-to-moderate hearing loss as "Our forgotten children."

The amount of research about the effects of hearing loss on children with milder degrees of hearing loss has increased since Davis's influential work, but the idea that mild or moderate hearing

loss is not a major threat to development is persistent. For example, Ching and colleagues (2013) found no advantage for early amplification for children with mild-to-moderate hearing loss and concluded:

> . . . most of the children with hearing aids at the time of assessment had a mild or moderate loss. Perhaps the auditory stimulation these children received unaided was sufficient to enable development of the auditory cortex, such that when hearing aids were later provided, the children were able to make just as good use of the signals received as children who received their hearing aids earlier. (p. 548)

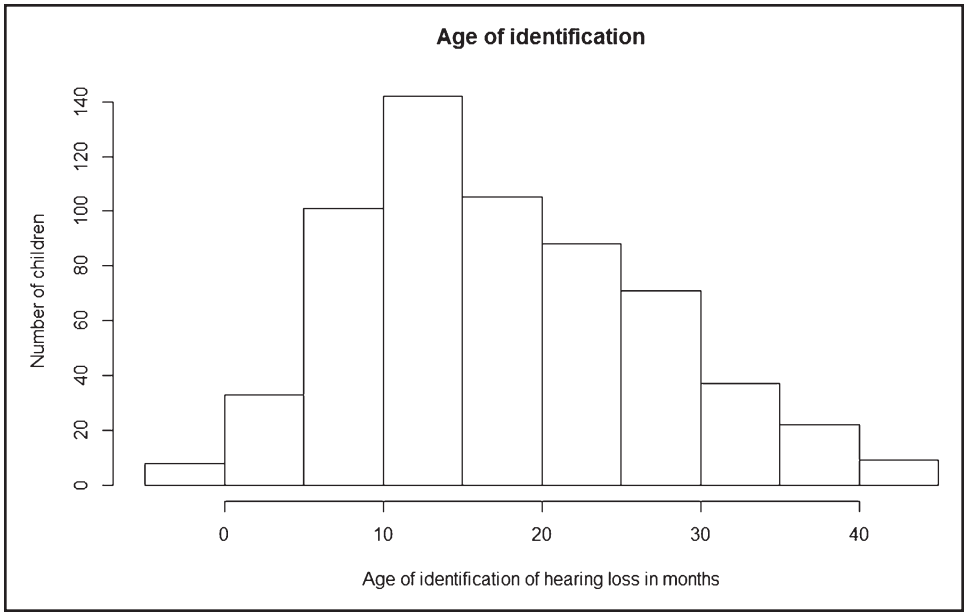
The clear implication of this statement is that children with mild-to-moderate hearing loss have sufficient residual hearing without amplification to provide a foundation for auditory development and learning. However, examining only the potential advantages related to the timing of amplification clearly ignores the influence of factors such as how well the child's hearing aids restore audibility for speech, how often the child is wearing his/her hearing aids, and the type of intervention or environment to which the child is exposed. As is discussed in the next section of the chapter, some of the limited effects of the timing of amplification in recent research is likely related to the fact that most children who are hard of hearing receive amplification within the first few months of life (Holte et al., 2012). The shift to lower ages of hearing aid fitting before and after the implementation of universal newborn hearing screening is shown in Figure 1–1. This is a contrast to early research where the average age of identification was over 2 years of age (Moeller, 2000). As a result, research has shifted toward the other factors, in addition to the timing of amplification that could affect developmental outcomes in children who wear hearing aids.

Subsequent research has attempted to quantify the impact of child- and family-specific characteristics, timing and quality of early intervention, hearing aid effectiveness, and language environment to name just a few. In the following sections, the features that have been identified in research as the most influential associates of development in children who are deaf or hard of hearing are discussed. In particular, a recent theoretical perspective, known as the model of cumulative auditory experience, is highlighted. The model of cumulative auditory experience includes multiple facets of the child's auditory abilities, their environment, and intervention, in an attempt to enumerate the quality and quantity of a child's auditory experience over time. Clinicians can use their knowledge of these factors to guide families in important clinical decisions regarding the types of interventions that might be most successful for the children that they serve.

MALLEABILITY

There are two broad categories of features that have been identified as influencing developmental outcomes in children who are deaf or hard of hearing: malleable and nonmalleable factors. Malleable factors are any aspects of the child, his or her environment, or interventions that can be changed with minimal effort. One example of a malleable factor that receives considerable emphasis throughout this text is the audibility of speech provided by the child's hearing aid. Speech audibility from a hearing aid is malleable in the sense that if a child comes into the clinic with a hearing aid that is not providing an adequate amount of audibility for their degree of hearing loss, the audiologist can adjust the hearing aid to maximize the child's access to speech. A number of other malleable factors have been shown to influence developmental outcomes in children.

In contrast, nonmalleable factors are features related to the child, their environment, or interventions that cannot be modified easily. One example of a nonmalleable factor is the socioeconomic status of the child's family. Low family socioeconomic status can have negative effects on development for children who are otherwise typically developing, and represents an additional risk for developmental delays in children who are hard of hearing. Sadly, the socioeconomic status of the family cannot be easily modified through intervention. Changes in socioeconomic status at the level of individual families are difficult to



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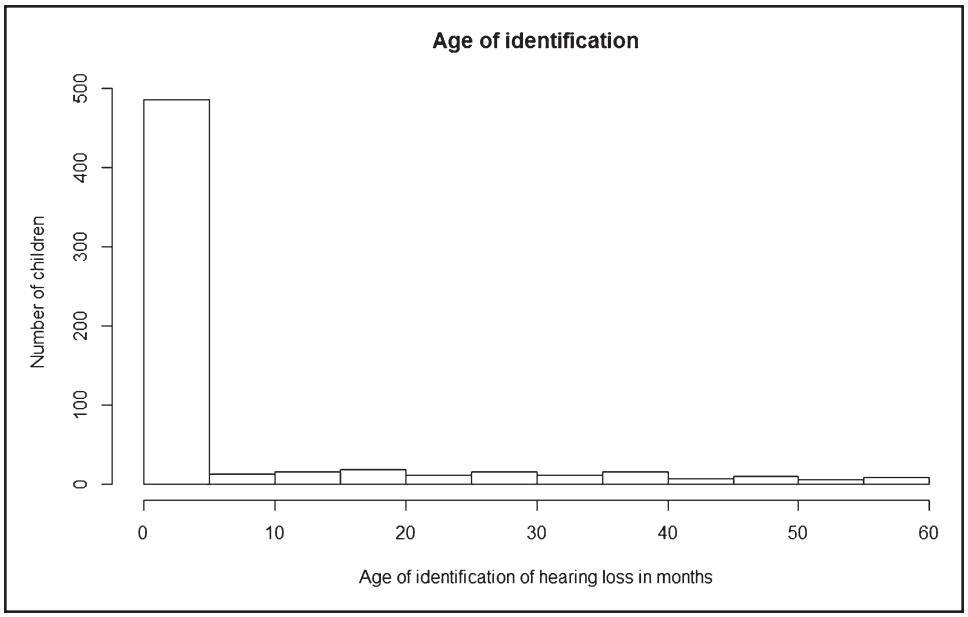

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FIGURE 1–1. Age of identification of hearing loss prior to newborn hearing screening based on data from Moeller (2000) (**A**), compared to age of identification of hearing loss after newborn hearing screening based on data from Holte et al. (2012) (**B**).

achieve even with major public policy and societal changes. However, being aware that socioeconomic status is a potential risk factor for additional developmental concerns in children who are hard of hearing can allow clinicians to provide supports to ensure that families have access to intervention services for their children. Nonmalleable factors may not be directly modifiable, but clinicians

should be aware of these factors so that they can assess the risk for developmental delays related to these factors.

Malleable and nonmalleable factors also may interact in ways that have important clinical implications. The audibility of speech sounds through the hearing aid use has both malleable and nonmalleable influences. For example, Figure 1–2 displays the relationship between audibility and degree of hearing loss for children who are fit to the Desired Sensation Level (DSL) (Scollie et al., 2005) multistage algorithm, which is a popular hearing aid prescriptive approach for children.

As the child's degree of hearing loss increases, the amount of audibility that is prescribed, and that can be provided, decreases. This relationship exists because of how sensorineural hearing loss affects the listener's dynamic range. The dynamic range of hearing is defined as the difference between the listener's hearing thresholds and the level where loudness discomfort occurs. As hearing loss increases, the listener's thresholds increase, but the sound level where loudness discomfort occurs remains relatively stable and can even become less for some listeners. The net effect is that the dynamic range of hearing, which can span 100 dB in listeners with normal hearing, can be reduced to only 20 to 30 dB in listeners with severe or profound sensorineural hearing loss. The child's degree of hearing loss, therefore, is a nonmalleable factor that places constraints on the amount of audibility for speech that can be prescribed and achieved with amplification. However, aided audibility also has an important malleable aspect. Providing a hearing aid fitting that closely approximates prescriptive targets for the child's degree of hearing loss allows audiologists to provide consistent audibility. The nonmalleable facet of audibility related to the degree of hearing loss can by mitigated by the malleable aspect related to how closely the hearing aid is fit to prescriptive targets. In one study, the amount of variability in aided audibility related to how well the hearing aids were fit was equal to the amount of variability related to degree of hearing loss in a large group of children who wore hearing aids (McCreery, Bentler, & Roush, 2013). An understanding of malleable and nonmalleable factors that are associated with developmental outcomes in children who are deaf or hard of hearing is an essential foundation for understanding why children who are hard of hearing exhibit such a wide range of developmental outcomes. The model of cumulative auditory experience that is the key framework of this text incorporates both malleable and nonmalleable factors in an attempt to create a model that reflects the realities of providing clinical services to children who wear hearing aids. The interactions between these factors must also be considered, as the effects of hearing loss on development in children are inherently complex and multivariate. The interactions, in particular, may be important to discuss with families to avoid overly simplistic conclusions about a child's potential for development.

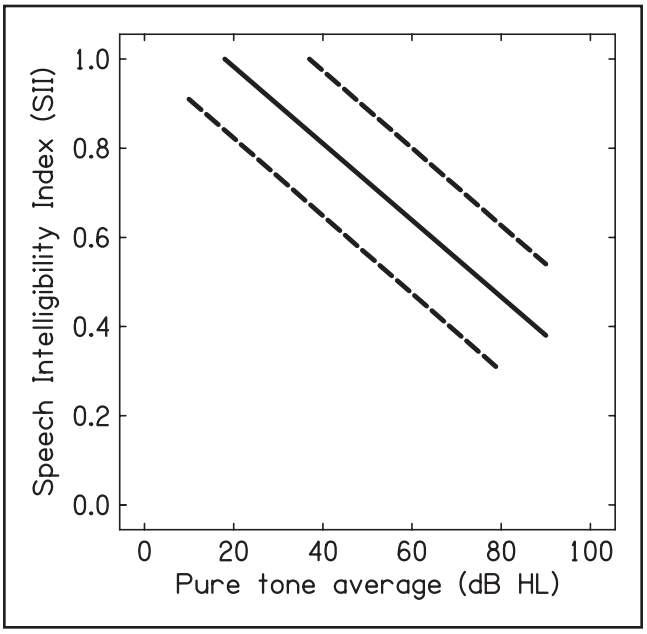

FIGURE 1–2. Aided audibility as a function of degree of hearing loss for children fitted to the Desired Sensation Level (DSL) algorithm, based on data from McCreery et al. (2013).

Nonmalleable Factors

As noted in the previous section, nonmalleable factors are any characteristics of the child, environment or intervention that cannot easily be modified. Nonmalleable factors have been widely

studied because they are often easy to measure or document. An exhaustive discussion of nonmalleable factors that affect developmental outcomes in children who are deaf or hard of hearing is beyond the scope of this clinically focused overview, but particular attention will be given to nonmalleable factors that could influence clinical interventions. The child's degree of hearing loss, the age of identification/hearing aid fitting/intervention, socioeconomic status, presence of additional disabilities aside from hearing loss, and gender are all nonmalleable factors that have been reported in previous studies.

Degree of Hearing Loss

As already noted in earlier sections of this chapter, the degree of hearing loss has been an effective predictor of developmental outcomes in children who are deaf or hard of hearing in some studies. Even a lay person with limited experience working with children who are deaf or hard of hearing might make the intuitive prediction that children who have more hearing loss would experience greater impact on their development than peers with less hearing loss. However, the pattern of data in the research literature has not always confirmed this prediction. Children with greater degrees of hearing loss have had poorer outcomes in speech and language than peers with milder degrees of hearing loss in some studies (Ching et al., 2010; Ching et al., 2013; Fitzpatrick, Crawford, Ni, & Durieux-Smith, 2011; Fitzpatrick, Durieux-Smith, Eriks-Brophy, Olds, & Gaines, 2007; Hood, 1949; Sininger, Grimes, & Christensen., 2010; Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014; Tomblin et al., 2015; Wake, Hughes, Poulakis, Collins, & Rickards, 2004; Yoshinaga-Itano, Coulter, & Thomson, 2000 Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998), but not in others (Davis et al., 1986; Gilbertson & Kamhi, 1995; Moeller 2000). Similarly, children who have more significant degrees of hearing loss also show greater deficits in speech recognition compared to peers with less hearing loss (Blamey et al., 2001; Davidson & Skinner, 2006; McCreery et al., 2015). This apparent inconsistency across studies can be confusing for parents and caregivers of children who are deaf or hard of hearing, who may expect that their child with mild hearing loss might develop typically or that their child with profound hearing loss might not be able to communicate using spoken language.

There are many reasons why degree of hearing loss by itself is not a singular predictor of development in children who are deaf or hard of hearing. Degree of hearing loss is often represented as a single number, such as the pure-tone average, which is the arithmetic mean of the audiometric thresholds at 500 Hz, 1000 Hz, and 2000 Hz (and sometimes 4000 Hz additionally). In some cases, degree of hearing loss is represented by the broad semantic categories of mild, moderate, severe, or profound. Attempting to reduce hearing down to a single number or category will mean that there are often significant individual differences between children who have similar pure-tone averages or the same degree of hearing loss. Children with similar pure-tone averages can have varying configurations of hearing loss that could impact their access to speech in different ways, as shown in the example in Figure 1–3.

Additionally, degree of hearing loss reflects unaided hearing, when most children who are deaf or hard of hearing will spend most of their day using hearing aids or a cochlear implant. Children with cochlear implants are an interesting example of how the effect of degree of hearing loss has changed over time. In some recent investigations, children with cochlear implants have more favorable developmental outcomes compared to peers with hearing aids (e.g., Ching et al., 2013), despite having severe or profound degrees of hearing loss. For this reason, many researchers include measures of aided hearing, including aided audibility for speech and aided speech recognition abilities in addition to estimates of unaided hearing when attempting to evaluate risk for developmental delays in children with hearing loss.

Finally, evidence from children who have mild or unilateral hearing loss (which is discussed in greater detail in Chapter 9) suggests that even minimal disruptions in audibility can have an impact on communication development. A paper from Walker et al. (2015) included three groups of children with similar degrees of mild hearing loss: full-time hearing aid users, part-time hearing aid users and children who did not use amplifi-

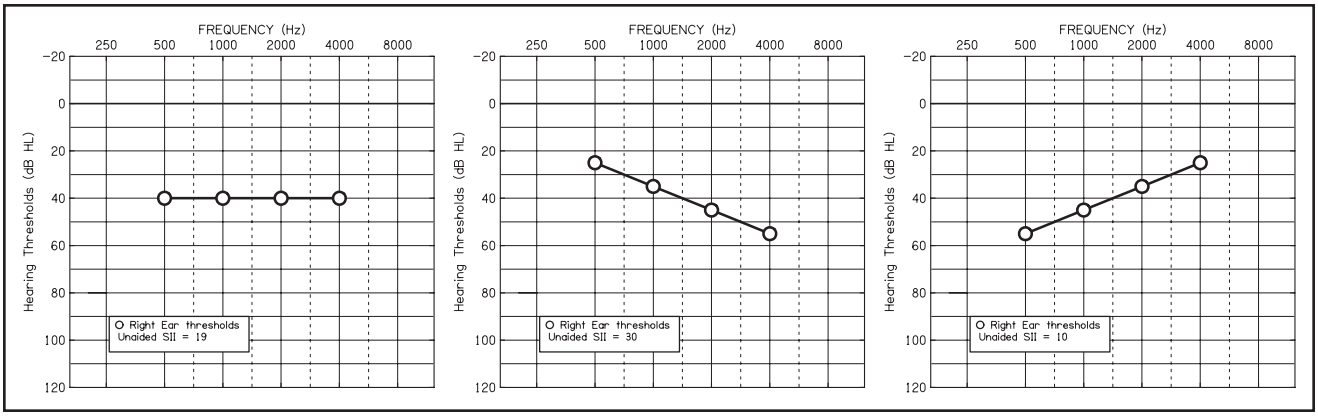

FIGURE 1–3. Three audiograms with the same pure-tone average (PTA) can have very different effects on the audibility of speech. Note the differences in the unaided Speech Intelligibility Index (SII) across the examples for children who have a PTA of 40 dB HL.

cation. Despite having similar degrees of hearing loss, the children who did not wear amplification or receive early intervention services had poorer speech and language outcomes in several specific domains compared to the part-time or full-time hearing aid users. This demonstrates not only that even mild hearing loss can affect developmental outcomes, but also that degree of hearing loss does not adequately reflect the factors related to amplification and intervention that could also influence developmental processes in children who are deaf or hard of hearing.

Age of Identification/Hearing Aid Fitting/Intervention

Over the last two decades, questions about the timing of intervention for children who are deaf or hard of hearing have been conducted to evaluate the need for universal newborn hearing screening and early intervention programs. Many early studies contrasting developmental outcomes for children with different timing for identification and intervention were based on opportunistic samples in areas where universal newborn hearing screening and early intervention programs were implemented at varying times in the same hospital or educational areas. The sequential implementation of newborn hearing screening and early intervention programs created naturally occurring early- and later-identified groups of children who were otherwise very similar. In one of the first studies to evaluate questions about timing of early identification and intervention, Yoshinaga-Itano and colleagues (1998) found higher language quotients for children who were enrolled in early intervention before 6 months of age, compared to children who were enrolled in early intervention at later ages. This finding of improved language outcomes has been replicated in numerous studies subsequently (Calderon & Naidu, 1999; Kennedy et al., 2006; Moeller, 2000; Sininger et al., 2010) and expanded to long-term reading outcomes as children get older (Pimperton & Kennedy, 2012; Pimperton et al., 2016).

Like degree of hearing loss, however, there are also exceptions that have not found similar advantages for early identification and intervention (Ching et al., 2013). Additionally, many of the studies contrasting early- and later-identified children who are deaf or hard of hearing have been criticized for a lack of true random assignment (Nelson, Bougatsos, & Nygren, 2008). Another challenge in more recent studies is that the ages of identification, fitting of hearing aids, and early intervention are occurring more uniformly early. For example, one recent longitudinal study found that 76% of children who were hard of hearing were identified through newborn hearing screening and the median age at hearing aid fitting was just 7 months of age (Holte et al., 2012). With early identification becoming more consistent, the ability to document the advantages for early identification over a shrinking group of late-identified