Research Article

Time-Gated Word Recognition in Children: Effects of Auditory Access, Age, and Semantic Context

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Purpose: We employed a time-gated word recognition task to investigate how children who are hard of hearing (CHH) and children with normal hearing (CNH) combine cognitive–linguistic abilities and acoustic–phonetic cues to recognize words in sentence-final position.

Method: The current study included 40 CHH and 30 CNH in 1st or 3rd grade. Participants completed vocabulary and working memory tests and a time-gated word recognition task consisting of 14 high- and 14 low-predictability sentences. A time-to-event model was used to evaluate the effect of the independent variables (age, hearing status, predictability) on word recognition. Mediation models were used to examine the associations between the independent variables

(vocabulary size and working memory), aided audibility, and word recognition.

Results: Gated words were identified significantly earlier for high-predictability than low-predictability sentences. First-grade CHH and CNH showed no significant difference in performance. Third-grade CHH needed more information than CNH to identify final words. Aided audibility was associated with word recognition. This association was fully mediated by vocabulary size but not working memory.

Conclusions: Both CHH and CNH benefited from the addition of semantic context. Interventions that focus on consistent aided audibility and vocabulary may enhance children's ability to fill in gaps in incoming messages.

The process of recognizing words in the incoming speech signal is complex and interactive. Listeners can use word-initial acoustic–phonetic characteristics of the input to activate lexical candidates, allowing them to recognize lexical items before they hear the entire word (Allopenna, Magnuson, & Tanenhaus, 1998; Marslen-Wilson, 1987; McMurray, Samelson, Lee, & Tomblin, 2010). Simultaneously, listeners use semantic context to facilitate word recognition, particularly in degraded listening situations (Nitttrouer & Boothroyd, 1990; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). Therefore, efficient and accurate language processing requires coordination of both lower level perceptual skills and higher

level cognitive–linguistic abilities. In children who are hard of hearing (CHH), limited audibility interferes with perception. At the same time, linguistic skills that would normally support speech recognition may be immature due to limited auditory experience in early childhood (Tomblin et al., 2015). Unfortunately, there is a paucity of data on how audibility and cognitive–linguistic skills interact to affect spoken word recognition for CHH (Eisenberg et al., 2007; Jerger, 2007). The primary goal of the current article is to examine how auditory access, age, and semantic context affect the amount of auditory information that is required for word recognition in children. A secondary goal is to investigate whether vocabulary and working memory mediate the relationship between aided audibility and spoken word recognition in CHH.

The current study employs a time-gated word recognition task to investigate how children combine cognitive–linguistic and acoustic–phonetic cues to perceive and predict an incoming message (Dollaghan, 1998; Evans, Gillam, & Montgomery, 2018; Grosjean, 1980). In the gating paradigm, the listener hears stimuli in which acoustic–phonetic information has been removed from the target word in successive steps. The gated word may be presented in isolation (Collison, Munson, & Carney, 2004) or as the final word

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in a sentence (Lewis et al., 2017). After each presentation, the listener guesses the target word. The duration of the target word (i.e., the amount of acoustic–phonetic information) is increased until the participant accurately identifies the target word or until all of the acoustic–phonetic information is presented. Listeners need strong perceptual skills to efficiently decode the acoustic–phonetic information. When the target word occurs at the end of a highly predictable sentence context, the listener may also utilize semantic knowledge to recognize the target word using less acoustic–phonetic information (Patro & Mendel, 2018). Working memory may also come into play because the listener has to encode and maintain input while trying to access a lexical item from long-term memory (Rönnerberg et al., 2013).

Gating tasks have several advantages over single-word or sentence-level repetition measures, which are traditionally used to assess word recognition skills in CHH (McCreery, Walker, Spratford, Oleson, et al., 2015; Sininger, Grimes, & Christensen, 2010; Stiles, Bentler, & McGregor, 2012). One advantage is that gating tasks show us how efficiently an individual can identify a word with just word-initial information, whereas repetition tasks can only inform us of whether an individual can accurately perceive and produce a whole word (Patro & Mendel, 2018). Determining the efficiency with which one can identify a word can inform us about the robustness of phonological and lexical representations (Dollaghan, 1998; Mainela-Arnold, Evans, & Coady, 2008). Another advantage is that we can experimentally control the amount of acoustic information the listener receives. Because listeners are not initially exposed to the entire signal, they must hold the incoming signal in memory while searching their lexicons to select the most likely word based on an incomplete acoustic representation of the target. Thus, we can simultaneously examine demands on both cognitive and linguistic abilities, such as vocabulary knowledge and working memory capacity (Klein, Walker, Kirby, & McCreery, 2017; Lunner, Rudner, & Rönnerberg, 2009). A third advantage of gating tasks is that they are more representative of real-world listening situations than traditional word recognition measures. In complex listening environments, listeners are often required to understand speech in less-than-ideal conditions, often-times when acoustic–phonetic information is partially or fully masked. Listeners must employ their cognitive and linguistic skills to effectively use available semantic context when acoustic–phonetic information is lacking. With strong cognitive–linguistic skills, a listener can fill in the missing acoustic–phonetic information to understand what is being said and remain an active participant in the conversation or an active listener in the classroom.

The gating task has been used to test developmental theories of word recognition. One such theory is the lexical restructuring hypothesis, which has been proposed to explain how children recognize words (Garlock, Walley, & Metsala, 2001; Metsala, 1997; Nittrouer, Caldwell-Tarr, Low, & Lowenstein, 2017; Walley, 1993). The lexical restructuring hypothesis posits that, early in development, young children show less sensitivity to phonetic detail than

older children or adults. As more words are added to a child's vocabulary, this less detailed manner of recognizing speech becomes unwieldy because the child needs to discriminate among many words in their lexicon that sound similar. Children learn to deal with the issue of a crowded mental lexicon by progressively developing more fine-grained analyses of the phonological content of words. In essence, lexical representations are restructured as the child becomes more sensitive to the phonological information or sublexical units within words. This segmentation of sublexical units allows for more detailed and efficient storage of lexical items (Walley, 1993).

Evidence from gating tasks and other experimental paradigms suggest that typically developing children show a gradual transition from less robust and imprecise lexical representations to phonologically detailed, adultlike representations through middle childhood (Elliott, Hammer, & Evan, 1987; Garlock et al., 2001; Metsala, 1997; Nittrouer & Studdert-Kennedy, 1987; Storkel, 2002). Nittrouer and Studdert-Kennedy (1987) found that 7-year-olds were better able to differentiate sublexical units compared to 3- to 5-year-olds. Metsala (1997) tested 7-, 9-, and 11-year-olds and adults on a gated word recognition measure and found that 11-year-olds required less acoustic–phonetic information to recognize words compared to 7-year-olds. To date, few researchers have examined developmental changes in lexical representations for CHH. It is unclear whether CHH follow the same developmental time course in lexical restructuring compared to children with normal hearing (CNH), although it has been suggested that signal degradation and limited speech audibility related to hearing loss (HL) could make lexical restructuring challenging (Nittrouer et al., 2017). Thus, CHH may experience a protracted stage of inefficient lexical processing, in effect requiring more acoustic–phonetic information to recognize words. This reduction in efficiency can slow down word recognition, which may have cascading effects on sentence comprehension, vocabulary development, and reading (Borovsky, Burns, Elman, & Evans, 2013; Metsala, 1997; Snowling, Goulandris, Bowlby, & Howell, 1986; Wagner & Torgesen, 1987).

Only a few studies have utilized the gating paradigm with individuals with HL. Collison et al. (2004) tested 15 adults with postlingual deafness who used cochlear implants (CIs) and 15 age-matched adults with normal hearing on a gated monosyllabic word recognition task. The adults with CIs required significantly more gates to recognize words compared to the adults with normal hearing. Vocabulary skills and nonverbal IQ were not associated with gated word recognition in the individuals with CIs. However, the small group of adult CI users was heterogeneous with respect to both their hearing histories and electrical signal that they received from their CIs. This variation in auditory access and experience may have obscured the ability to find a relationship between cognitive–linguistic skills and word recognition. It is also possible that presenting monosyllabic words in isolation, rather than gating the last word in sentences, weakened the association between cognitive–linguistic skills and word recognition because

individuals with stronger higher level skills were unable to utilize semantic context to support word recognition.

Lewis et al. (2017) employed a gated word recognition paradigm with 16 children with mild-moderate HL and an age-matched group of 16 CNH. The gating task in Lewis et al. differed from Collison et al.'s (2004) task, as it involved sentences in which the final word was gated, rather than monosyllabic stimuli. The stimuli also varied in terms of semantic context, in that the sentences consisted of 15 high-predictability sentences and 15 low-predictability sentences. This manipulation of context allowed the researchers to investigate how well the children were able to make use of semantic context to support word recognition. Both groups benefited from the addition of context, but there was a significant interaction between hearing status and predictability. CHH were able to perform, as well as CNH, when provided with semantic context but required more acoustic-phonetic information for word recognition in low-predictability contexts.

There are several important methodological factors to consider in the study by Lewis et al. (2017). First, they presented the test stimuli via a hearing aid (HA) simulator to the CHH, so each child with HL had optimized audibility for the stimuli in the experiment. While the optimized audibility provided by the HA simulator helped to minimize differences in auditory access during the experiment, CHH vary in the degree to which audibility is provided through their own HAs (McCreery, Walker, Spratford, Bentler, et al., 2015). Thus, presenting stimuli via children's HAs may be more representative of real-world listening. Because of the optimized audibility, Lewis et al. also could not examine a fundamental question of how individual differences in aided audibility are associated with variation in outcomes (Moeller & Tomblin, 2015). Second, although standardized language measures were collected, Lewis et al. did not examine the associations between linguistic skills and gating performance. Third, they did not collect data on working memory skills, which may support word recognition in children (McCreery, Spratford, Kirby, & Brennan, 2017; but see Magimairaj, Nagaraj, & Benafield, 2018). Finally, the study included a wide age range (5–12 years), which limited the ability to examine developmental changes in spoken language processing because there were too few children at each age. Five- to 7-year-old CNH are weaker at taking advantage of semantic context during gated word recognition tasks than 8- to 10-year-olds (Craig, Kim, Rhyner, & Chirillo, 1993), but developmental comparisons of the effects of semantic context and hearing status on spoken word recognition have not been thoroughly examined.

In the current study, we investigated the association between aided audibility and word recognition skills, as well as whether language and memory interact with aided audibility to facilitate performance in a complex listening task. The direct association between amount of auditory access and word recognition has traditionally been assessed via degree of HL, measured in terms of pure-tone average (PTA; Blamey et al., 2001; Sininger et al., 2010). An alternative technique is to measure aided speech audibility,

quantified using the Speech Intelligibility Index (SII; American National Standards Institute, 1997). SII is a metric that reflects the proportion of the speech spectrum that is audible without amplification (unaided SII) or given the acoustic gain that the HA provides (aided SII). Aided SII more accurately represents the everyday listening experiences of CHH than unaided PTA. It can be used to account for amplification characteristics of HAs, including variability in ear canal acoustics and amount of access to the speech spectrum at soft, conversational, or loud levels (Stiles et al., 2012). Although degree of HL and aided audibility are strongly correlated, aided audibility provides a unique contribution to listening outcomes because it is influenced by the configuration of HL and represents access to the acoustic cues provided by the HAs. Stiles et al. (2012) and McCreery, Walker, Spratford, Oleson, et al. (2015) both found that aided SII was a stronger predictor of word repetition skills than PTA, suggesting that SII is a better metric of functional hearing abilities in CHH.

Based on the findings of Stiles et al. (2012) and McCreery, Walker, Spratford, Oleson, et al. (2015), we might predict that greater auditory access leads directly to faster word recognition. However, it is also possible that lower level auditory access indirectly supports word recognition via its association with higher level skills, which then affect word recognition. Greater aided audibility has a positive impact on vocabulary development in CHH (Tomblin et al., 2015; Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014; Walker, Redfern, & Oleson, in press), likely because CHH with greater aided audibility have more consistent access to spoken language input. Children with HL with better language skills tend to have better speech recognition compared to children with poorer language skills (Blamey et al., 2001; Davidson, Geers, Blamey, Tobey, & Brenner, 2011; Klein et al., 2017). Stronger working memory skills also have a positive impact on speech recognition in degraded listening conditions for CNH (McCreery et al., 2017; Osman & Sullivan, 2014) and CHH (McCreery, Walker, Spratford, Oleson, et al., 2015), although other researchers have reported finding a minimal impact of working memory on speech understanding in noise (Magimairaj et al., 2018). Both vocabulary and working memory are positively correlated with aided audibility in CHH (Stiles et al., 2012; Tomblin et al., 2015, 2014). None of these studies, however, have attempted to disentangle the contributions of each of these variables on word recognition after controlling for the influence of the other factors. In addition to direct relationships between audibility and speech recognition, it is possible that audibility indirectly supports speech recognition via its associations with vocabulary and working memory.

This study uses mediation models to address this specific question (Baron & Kenny, 1986). As we already stated, previous researchers have demonstrated a strong association between the independent variable ("X" = aided audibility) and the dependent variable ("Y" = spoken word recognition). A mediation analysis can inform us of whether a third variable ("M" = vocabulary or working memory)

acts a mediating variable in the sequence of $X \rightarrow M \rightarrow Y$. Variables are said to function as mediators when they meet the following conditions (see Figure 1): (a) Variance in the independent variable accounts for variance in the mediator (Path A); (b) variance in the mediator accounts for variance in the dependent variable (Path B); and (c) when Paths A and B are controlled, the association between the independent and dependent variables (Path C) is no longer significant.

Use of mediation models has both clinical and theoretical applications in the current line of research. With regard to the fundamental processes underlying word recognition for individuals with HL, this research will inform theory by facilitating a more thorough understanding of the interdependencies between lower and higher level skills on word recognition. Studying these interactions also has important clinical implications, in that it can help to design more efficient and effective interventions that support listening in realistic environments. For example, if vocabulary and working memory are found to mediate the association between aided audibility and word recognition, this would indicate that intervention with CHH should focus on improving auditory access and cognitive-linguistic skills.

In summary, few studies have directly examined the underlying mechanisms that support word recognition efficiency in children with mild-to-severe HL. Specifically, we examined the amount of acoustic-phonetic information that children need to recognize words. The current study compared CHH to age-matched CNH at first and third grades using a gated word recognition task in a sentence context. Sentence predictability was varied to examine the effects of semantic context on word recognition. Measures of aided audibility, vocabulary skills, and working memory were collected to explore unique contributions of these factors to spoken word recognition.

The current study addresses the following research questions:

Question 1: What are the effects of age, hearing status, and predictability on spoken word recognition in a gating task? We predicted that younger children and CHH would require more acoustic-phonetic information to accurately identify words on the gating task than older children and CNH. We also predicted that participants would benefit

from high-predictability semantic context to identify target words. Based on Lewis et al. (2017), we predicted that there would be an interaction between hearing status and predictability: CHH would need more acoustic-phonetic information to identify words in low-predictability contexts compared to CNH, but the two groups would perform similarly when words were presented in high-predictability contexts.

Question 2: Does aided audibility directly influence time-gated word recognition? Do vocabulary size and working memory mediate the relationship between aided audibility and time-gated word recognition? Based on Stiles et al. (2012) and McCreery, Walker, Spratford, Oleson, et al. (2015), we predicted that there would be a significant association between aided audibility and word recognition. Furthermore, we predicted that vocabulary size and working memory skills would fully mediate that relationship because of indirect effects of audibility on gating performance.

Method

Participants

Participants were recruited from two primary sites: University of Iowa and Boys Town National Research Hospital. Participating children used spoken English as their primary communication mode and had at least one primary caregiver who spoke English in the home. Children performed within 1.5 SDs of the norm-referenced mean on at least one of the two nonverbal subtests, Block Design and Matrix Reasoning, of the Wechsler Abbreviated Scale of Intelligence (Wechsler & Hsiao-pin, 2011) to qualify for participation. Vision was within normal limits or corrected to normal. Children who had motor impairments that precluded completing conventional audiometric testing or pointing to items on standardized tests (e.g., Peabody Picture Vocabulary Test) were excluded.

Hard-of-Hearing Group

Forty CHH in first or third grade participated (first grade, $n = 18$; third grade, $n = 22$). CHH presented with a permanent, bilateral HL, with the better-ear PTA (BEPTA) in the mild-to-severe range. BEPTA ranged from 15 to 76.25 dB HL ($M = 47.09$ dB HL, $SD = 14.47$). The child with the BEPTA of 15 dB HL was selected to participate by consensus of the research team due to the presence of a bilateral high-frequency HL. Better-ear aided SII ranged from 0.34 to 0.97 ($M = 77.92$, $SD = 14.51$). One third grader was not fit with HAs, so better-ear unaided SII was used for this child. First graders had a significantly earlier age at confirmation of HL compared to third graders, $t(28.3) = -2.35$, $p = .03$. There were no significant differences in age at HA fitting, BEPTA, or better-ear SII (all $ps > .05$) between first and third graders.

Normal Hearing Group

Thirty CNH (first grade, $n = 15$; third grade, $n = 15$) served as a comparison group. CNH had documented

Figure 1. Schematic of mediation models (Baron & Kenny, 1986).

hearing thresholds at or below 20 dB HL at 500, 1000, 2000, and 4000 Hz. Table 1 provides demographic characteristics about the CHH and CNH.

Procedure

All study procedures were approved by the University of Iowa and Boys Town National Research Hospital Institutional Review Boards. As part of a larger longitudinal study, CHH and CNH participated in one 3- to 4-hr research visit during the school year or the summer after first or third grade. The test battery consisted of audiologic assessment, HA verification, word recognition testing, and cognitive and linguistic assessments.

Audiologic Assessment

Participants received hearing assessments conducted by certified pediatric audiologists. For CHH, air-conduction thresholds were obtained at 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. Ear-specific thresholds were obtained with insert earphones or supra-aural headphones. The better-ear PTA at 500, 1000, 2000, and 4000 Hz was calculated for data analysis. For CNH, a hearing screen was conducted at 15 or 20 dB HL at 500, 1000, 2000, and 4000 Hz.

HA Verification and Audibility Measures

The audiologist used conformity measures to evaluate HA function (American National Standards Institute, 2003). The SII (American National Standards Institute, 1997) was calculated to quantify unaided and aided audibility. The unaided SII is calculated by estimating the audibility of a speech signal based on the listener's hearing thresholds. The aided SII is the audibility of the amplified long-term average speech spectrum signal through the HAs. A score of 0 indicates that none of the speech spectrum is audible, and a score of 1 indicates full audibility.

When the HA response could not be measured in the child's ear, simulated real-ear measures were used to calculate aided and unaided SII. Probe microphone measures

were initially used to quantify the real-ear to coupler difference (Bagatto et al., 2005). HA verification was then completed in the 2-cc coupler. Audioscan Verifit software (Cole, 2005) calculated unaided and aided SII for amplification programed to users' settings using the standard male speech signal (carrot passage; Cox & McDaniel, 1989) presented at average conversational levels (60 or 65 dB SPL) following American National Standards Institute (1997). Indices of aided SII for the average level of input were computed for 35 children who had been fitted with acoustic HAs. Four children used a softband bone-anchored HA; SII could not be calculated for these children. One third grader was not fit with HAs, so better-ear unaided SII was used for this child.

Language and Working Memory Assessments

Examiners administered standardized tests of language and memory abilities. The Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; Dunn & Dunn, 2007) is a standardized test of receptive vocabulary. The examiner says a word that corresponds to one of four pictures on a page that is presented to the participant. The participant responds by pointing to the picture that corresponds with the target word. The Automated Working Memory Assessment (Alloway, 2007) is a computer-based test of working memory skills. In this study, we utilized the Odd One Out subtest, which is a visual-spatial complex working memory span task. The participant sees three shapes in a three-square matrix on a computer screen. Two of the shapes are the same, and one is different. The participant points to the shape that is the “odd one out.” The participant is then shown three empty boxes and indicates where the odd shape was located. The task is administered using a span procedure, in which the participant is asked to indicate the location of an increasing number of items. When four out of six spans within a set are identified correctly, the participant moves to the next level and the span increases by one item. The task is discontinued after three incorrect span responses within a set.

Table 1. Demographic information about the participants.

Test variable	First-grade CHH (<i>n</i> = 20)	Third-grade CHH (<i>n</i> = 20)	First-grade CNH (<i>n</i> = 15)	Third-grade CNH (<i>n</i> = 15)
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)
Age (years)	7.5 (0.33)	9.42 (0.39)	7.42 (0.43)	9.19 (0.23)
Maternal education level (years)	15.83 (1.92)	15.50 (3.05)	15.46 (4.44)	16.22 (2.73)
PPVT SS	108.72 (15.12)	105.91 (13.94)	110.26 (9.19)	112.44 (8.06)
TROG SS	103.05 (13.55)	104.18 (12.75)	107.73 (10.94)	108 (7)
AWMA Odd One Out SS	115.33 (14.14)	109.23 (13.86)	109 (18.22)	114.89 (10.56)
BEPTA (dB HL)	46.25 (13.73)	47.78 (15.33)	< 20	< 20
Better-ear aided SII	80.33 (13.10)	75.50 (15.91)	NA	NA
Age at HL confirmation (months)	4.78 (8.01)	15.98 (20.51)	NA	NA
Age at HA fit (months)	8.11 (15.84)	18.81 (20.53)	NA	NA

Note. CHH = children who are hard of hearing; CNH = children with normal hearing; PPVT = Peabody Picture Vocabulary Test–Fourth Edition; SS = standard score; TROG = Test of Reception of Grammar; AWMA = Automated Working Memory Assessment; BEPTA = better-ear pure-tone average; SII = Speech Intelligibility Index; HL = hearing loss; HA = hearing aid.

Gating Stimuli

The stimuli for the gating task consisted of 14 high-predictability sentences and 14 low-predictability sentences spoken by a female adult. High- and low-predictability sentences were chosen from a set of Speech Perception in Noise sentences (Bilger, Nuetzel, Rabinowitz, & Rzezczowski, 1984). The high-predictability sentences were determined to be highly predictable by the semantic and syntactic context of the sentence that facilitates the task of selecting the target word (e.g., “Tree trunks are covered with...” with the target word being “bark”). Lewis et al. (2017) confirmed predictability of the sentences; 15 children aged 5–12 years listened to or read the sentences and were able to correctly guess the final word. The low-predictability sentences did not contain semantic context that aided in selecting the final word; however, the sentences were syntactically correct (“He remembered the...” with the target word being “bridge”). The target words in the low-predictability sentences were selected to closely resemble the target words in the high-predictability sentences through their syllable structure, manner, and voicing.

Each sentence ended with a gated target word. The first gate started at 0 ms from the onset of the word (i.e., none of the target was presented) to determine whether the participants could correctly identify the final word using context cues and possible coarticulation cues (Dahan, Magnuson, Tanenhaus, & Hogan, 2001). The following gate was gated at 100 ms from the onset of the word and continued gating by 50-ms increments until the entire word was presented. Each presentation included the sentence leading up to the gated target word and the target word gate. The Appendix lists the high- and low-predictability sentences. The target words in each of the two sentence predictability groups (high vs. low) did not differ significantly in terms of average neighborhood density, average phonotactic probability, and average word frequency. Table 2 summarizes the lexical characteristics of the gated target words in the high- and low-predictability conditions (Storkel & Hoover, 2010). The 28 sentences and target words were modified to be within the expected vocabulary of our youngest participants (7 years old). For additional information regarding sentence construction, stimulus recording, and gate creation, see Lewis et al. (2017). Stimuli were the same as in Lewis et al., with the exception that “The boy hit the water with a splash” and “They talked about the desk.” The sentence with “splash” was removed due to concerns with

predictability based on pilot testing. “Desk” was randomly removed so there would be equal numbers of low- and high-predictability sentences.

Gating Procedure

Participants were individually tested in a sound booth or van equipped as a mobile testing unit. Each sentence was presented from a laptop connected to a MOTU sound card interface and a speaker system (M-Audio). The presented stimuli were calibrated at the location of the participant’s ear at 65 dBA.

The gating task took approximately 30 min. The participants were instructed that they would hear sentences and that the final word might be incomplete. Participants were instructed to verbally guess what they thought the last word might be. Before beginning, each participant completed a practice activity with the experimenter to ensure that they understood the task. During the task, participants moved onto the next stimulus item once they provided two sequentially correct responses (the acceptance point). If no acceptance point was reached, the participant heard the entire target word.

The presentation of the sentences started with a high-predictability sentence and then alternated between high- and low-predictability sentences until all 28 sentences were presented. Order of target words within the high- and low-predictability conditions was randomized. After the participant guessed the target word, the experimenter typed the child’s response and indicated on the computer whether the response was correct. For scoring purposes, responses of the target word that included plural bound morphemes were counted as correct (e.g., “kits” for “kit”). Compound words that included the target word (e.g., “flashlight” for the target “flash”) were not accepted as correct.

Statistical Analysis

We constructed a proportional hazards regression model to analyze time to acceptance point. This model was deemed more appropriate than analysis of variance and linear regression because the outcome measure (acceptance point) was a time-to-event measurement. Some target words by some participants were never identified, which meant that the data were right censored (i.e., the acceptance point never occurred, so the data were incomplete). The proportional hazards regression model allowed us to include the

Table 2. Lexical characteristics of the high- and low-predictability target words.

Target words	Length	Frequency of occurrence	Number of neighbors	Positional segment, <i>M</i>	Biphone, <i>M</i>	Neighborhood log frequency sum	Log frequency, <i>M</i>
High predictability	3.71	2.79	8.50	0.069	0.01	19.88	2.28
Low predictability	3.71	2.45	8.29	0.06	0.01	21.10	2.50
<i>p</i>	1	.2	.929	.80	.73	.85	.18

Note. Characteristics included word length, word frequency, number of neighbors, positional segment mean, biphone mean, neighborhood log frequency sum, and log frequency mean (Storkel & Hoover, 2010).

incomplete data without transforming or removing those trials from the analyses.

As there were multiple responses per child, a robust covariance estimate was used to accommodate the inherent within-subject correlations. The independent variables were hearing status (CHH or CNH), sentence predictability (low or high), and age (first or third grade). Due to significant differences in age at HL confirmation between first- and third-grade CHH, we controlled for age at confirmation in all analyses. We completed all analyses using SAS v9.4 and R v3.4.0, with a 5% significance level.

Hazard ratios were used for interpretation of the time-to-event models. A *hazard* is defined as the rate at which events happen. A *hazard ratio* is the comparison of rates between two different levels. It can be interpreted like an odds ratio in that it reflects the relative likelihood of one event occurring compared to another event; however, a hazard ratio differs from an odds ratio because it takes into account the timing of the event. A hazard ratio of 1 would indicate no differences between levels (i.e., CHH or CNH, low or high predictability, first or third grade) in the time it took to reach the acceptance point. A hazard ratio of greater than 1 for one group level compared to a reference level means that events occurred at a faster rate than the reference level. A hazard ratio of less than 1 indicates that events at a level occurred at a slower rate than the reference level. In the current analyses, low predictability, first grade, and CHH are coded as reference levels. Thus, a hazard ratio of greater than 1 for the variable sentence predictability would mean that the high-predictability sentences reached the acceptance point more quickly than the low-predictability reference level. A hazard ratio of greater than 1 for the variable age would mean that the third graders reached the acceptance point more quickly than the first-grade reference level. A hazard ratio of greater than 1 for the variable hearing status would mean that the CNH reached the acceptance point more quickly than the CHH reference level.

A proportional hazards regression model was also used to determine whether vocabulary size or working memory span mediated or accounted for the relationship between the SII and acceptance point. We used a single-mediator model to test these relationships, as described in the introduction (see Figure 1). A fully mediated effect occurs when Path C is zero after controlling for Paths A and B. A partially mediated effect occurs when there is a significant reduction in variance for Path C after controlling for Paths A and B, but Path C is not zero (Baron & Kenny, 1986).

The mediation variables (vocabulary and working memory) were analyzed separately, and age was accounted for in the models. In each of the mediation models, a counting process approach with a robust covariance estimate was used for significance testing to adjust for multiple measures on each subject. The mediation analyses were conducted with CHH only, as the question of interest related to how cognitive and linguistic skills mediated the relationship between aided audibility and gated word

recognition. We also conducted separate regression analyses examining how vocabulary and working memory were associated with gating performance in the CNH.

Results

Effects of Hearing Status, Age, and Sentence Predictability on Gating Task Performance

We constructed time-to-event models with grade, hearing status, and sentence predictability as independent variables. The independent variables were used to construct univariate and trivariate models. Interaction terms were included for the trivariate model, where appropriate.

Univariate Models

Figure 2 shows the effect of hearing status (CHH vs. CNH) on time to acceptance point after controlling for age at confirmation of HL. Our analysis showed that hearing status was significantly related to time to acceptance point ($p = .006$, hazard ratio = 1.21, 95% CI [1.06, 1.39]). CNH accurately identified gated words 1.21 times earlier than CHH. This finding was consistent with our predictions. Figure 3 shows the effect of sentence predictability (high vs. low). Consistent with our predictions, predictability was significantly associated with time to acceptance point ($p < .001$, hazard ratio = 3.74, 95% CI [3.29, 4.25]). The gated words from high-predictability sentences were accurately identified 3.74 times earlier than gated words from low-predictability sentences. Figure 4 shows the effect of age (first vs. third grade). Age did not have a significant influence on acceptance point ($p = .13$, hazard ratio = 1.10, 95% CI [0.97, 1.25]). This result was not consistent with our predictions that older children would identify words more quickly than younger children.

Figure 2. Effect of hearing status on time to acceptance point. Time to acceptance point is depicted on the x-axis, and the probability of reaching the acceptance point is on the y-axis. Higher curves reflect faster word recognition. CHH = children who are hard of hearing; CNH = children with normal hearing.

Figure 3. Effect of sentence predictability on time to acceptance point. Time to acceptance point is depicted on the x-axis, and the probability of reaching the acceptance point is on the y-axis. Higher curves reflect faster word recognition.

Trivariate Model

Next, we constructed a trivariate analysis to investigate possible interactions between age, hearing status, and predictability in one model, while still controlling for age at HL confirmation. A backward model selection was completed, starting with all interactions. The three-way interaction (age, hearing status, and predictability) was not significant. All of the two-way interaction terms were significant (hearing status and predictability, $p = .03$; hearing status and age, $p = .02$; predictability and age, $p = .001$). Because all of the two-way interaction terms were significant, the hazard ratios must be interpreted carefully because the effect of one independent variable varies depending on

Figure 4. Effect of age on time to acceptance point. Time to acceptance point is depicted on the x-axis, and the probability of reaching the acceptance point is on the y-axis. The two curves essentially overlap, reflecting no significant differences between first and third graders when hearing status and sentence predictability are collapsed.

the levels of the other independent variables. Table 3 shows the hazard ratios, 95% confidence intervals, and significance levels within each variable, after accounting for the levels of the other variables. For example, “NH vs. HH by high, first” compares the effect of hearing status on listening to high-predictability sentences in first grade.

Figure 5 shows the effect of hearing status in the trivariate analysis. There was no significant difference in time to acceptance point between CNH and CHH in first grade for low- and high-predictability sentences (see Figure 5A; $p = .81$ and $.26$, respectively). Third-grade CNH identified gated words significantly faster compared to third-grade CHH for both low- and high-predictability sentences (see Figure 5B; $p < .001$ and $p < .0001$, respectively). When we examined predictability, high-predictability sentences were always identified significantly faster than low-predictability sentences, even after taking hearing status or age into account (all $ps < .0001$). When we examined age, third-grade CNH identified words in low- and high-predictability sentences significantly faster than first-grade CNH ($p = .05$ and $p < .001$, respectively). In contrast, there was no significant difference between first- and third-grade CHH for low- or high-predictability sentences ($p = .18$ and $.25$, respectively).

Summary

For the univariate analyses, age was not associated with gating performance. High-predictability words were identified earlier than low-predictability words. CNH had earlier correct responses than CHH. The trivariate model showed that hearing status, age, and sentence predictability interacted to influence acceptance point in the gating task. The effect of predictability remained consistent in the trivariate model: When controlling for age and hearing status and their interaction, children identified high-predictability words earlier than low-predictability words. Age and hearing status can be considered in two ways—the two groups within each grade or each group across grades. In the former context, first-grade CHH showed no difference in gating performance compared to first-grade CNH. In contrast, third-grade CNH identified words earlier than third-grade CHH. An alternative way to view the results is by comparing CNH at first and third grades and CHH at first and third grades. In this latter context, third-grade CNH identified words earlier than first-grade CNH, but there was no significant difference between first- and third-grade CHH.

Effects of Auditory Access, Vocabulary Size, and Working Memory on Gating Task Performance in CHH

A proportional hazards model was used to determine whether vocabulary size or working memory skills mediated the relationship between aided audibility and time-gated word recognition. Because raw scores on the PPVT-4 and

Table 3. Hazard ratios, 95% confidence intervals (95% CIs), and significance levels for two-way interactions within the trivariate model.

Comparison	Hazard ratio	95% CI, lower	95% CI, upper	p
Hearing status				
NH vs. HH by high, first	1.23	0.86	1.77	.26
NH vs. HH by high, third	1.84	1.44	2.34	< .0001*
NH vs. HH by low, first	0.97	0.73	1.28	.81
NH vs. HH by low, third	1.44	1.19	1.75	< .001*
Predictability				
High vs. low by NH, first	3.89	3.16	4.79	< .0001*
High vs. low by NH, third	5.20	4.13	6.55	< .0001*
High vs. low by HH, first	3.05	2.48	3.74	< .0001*
High vs. low by HH, third	4.08	3.49	4.76	< .0001*
Grade level				
Third vs. first by NH, high	1.75	1.27	2.42	< .001*
Third vs. first by NH, low	1.31	1.00	1.71	.05*
Third vs. first by HH, high	1.18	0.89	1.55	.25
Third vs. first by HH, low	0.88	0.73	1.06	.18

Note. NH = normal hearing; HH = hard of hearing.

*Interaction significant.

Automated Working Memory Assessment Odd One Out task were used, chronological age was included as a continuous variable in the analyses.

Receptive Vocabulary

For the mediation model with PPVT-4 raw scores, a significant relationship was found between aided SII and the acceptance point ($\beta = .007$, $p < .006$). To determine whether vocabulary size functioned as a mediator in the significant relationship between aided audibility and time-gated word recognition, we first had to establish that variance in the independent variable (aided SII) accounted for

variance in the mediator (PPVT-4). We met this condition: Path A showed a significant relationship between aided SII and PPVT-4 scores ($\beta = .45$, $p < .0001$). The second step had to establish that variance in the mediator accounted for variance in the dependent variable (acceptance point). We also met this condition: In Path B, after controlling for aided SII and age, PPVT-4 scores still had a significant effect on acceptance point ($\beta = .007$, $p < .0001$). The third and final step required showing that the association between aided SII and acceptance point (Path C) was no longer significant. After controlling for PPVT-4 and age, the beta for SII and time to acceptance point decreased from .007 to

Figure 5. (A and B) Time to acceptance analysis for the trivariate model. Time to acceptance point is depicted on the x-axis, and the probability of reaching the acceptance point is on the y-axis. Panel a shows the significant effects of sentence predictability but lack of effect for age in the children who are hard of hearing. Panel b shows the significant effects of both age and sentence predictability for the children with normal hearing. CHH = children who are hard of hearing; CNH = children with normal hearing.

.004, which was not significant ($p = .09$). Because Path C was not significant after controlling for Paths A and B, these results are consistent with the hypothesis that vocabulary size fully mediated the relationship between aided SII and time-gated word recognition. Aided SII had an indirect effect on gated word recognition via its association with vocabulary.

Working Memory Span

For the mediation model with Odd One Out raw scores, there was again a significant direct effect between aided SII and acceptance point ($\beta = .007, p = .006$). There was also a statistically significant relationship between Odd One Out and aided SII (Path A; $\beta = .07, p < .001$). After controlling for SII and age, there was not a statistically significant effect of Odd One Out scores on time to acceptance point (Path B; $\beta = .014, p = .10$). Finally, after controlling for Odd One Out scores and age, SII was still significantly correlated with time to acceptance point (Path C; $\beta = .006, p = .01$). Thus, working memory does not appear to fully or partially mediate the relationship between SII and time-gated word recognition.

Effects of Vocabulary Size and Working Memory on Gating Task Performance in CNH

Time-to-event models with robust variance estimates were used to determine the relationship between the independent variables (receptive vocabulary and working memory) and time to acceptance point for CNH. Each independent variable was examined in a separate model controlling for age. In the model with PPVT-4 as the independent variable, PPVT-4 was not statistically significant ($p = .12$). In the model with Odd One Out as the independent variable, Odd One Out was not significant ($p = .06$). Thus, neither of the independent variables was significantly associated with gating performance in CNH.

Discussion

The aim of the current study was to use a time-gated word recognition task to examine the amount of auditory information that is required for children to recognize words in sentence-final position. We also examined whether cognitive or linguistic skills mediated the effects of aided audibility on word recognition for CHH. Because of its level of experimental control, the gating paradigm is a useful tool for investigating how higher level language comprehension, cognitive abilities, and auditory access interact to affect word recognition (Collison et al., 2004; Elliott et al., 1987; Garlock et al., 2001; Lewis et al., 2017; Metsala, 1997; Patro & Mendel, 2018). The findings from this study add to the current literature base on word recognition skills in CHH by providing insight into how auditory access, sentence predictability, age, vocabulary, and working memory affect the amount of information needed to identify words in complex listening situations.

The first objective of this study was to identify whether hearing status, age, and sentence predictability had an impact on spoken word recognition in a gating task. We predicted that CNH would reach the acceptance point earlier than CHH, words in high-predictability sentences would be identified earlier than low-predictability sentences, and older children would identify words earlier than younger children. Our results from the univariate analyses were mostly in line with our predictions. CHH had more difficulty identifying words with missing acoustic-phonetic information compared to CNH. This finding is consistent with Lewis et al. (2017), who also found a significant impact of hearing status in 5- to 12-year-old CHH and CNH. We also found that sentences with semantic context facilitated word recognition to a greater extent than ambiguous sentences. These results are in line with Lewis et al., as well as Patro and Mendel (2018), in which adult CI users, normal hearing adults listening to full-spectrum speech, and normal hearing adults listening to vocoded speech all showed faster word recognition on gating tasks with high-predictability context than low-predictability context.

In contrast to the main effects of hearing status and sentence predictability, we did not find a main effect for age. Performance on gating measures improves with age in typically developing populations (Elliott et al., 1987; Metsala, 1997; Walley, 1988). Lewis et al. (2017), however, did not find any effect of age on gating performance. The lack of an effect for age in Lewis et al.'s study may have been because they had small numbers of participants at each age level. In the current results, the lack of an effect of age was likely the result of the multiple significant two-way interactions. Specifically, we found that hearing status interacted with age: Third-grade CNH required less acoustic information to identify words compared to first-grade CNH, but third-grade CHH required the same amount of acoustic information as first-grade CHH. Another way to interpret this interaction is that third-grade CNH could recognize words more quickly than third-grade CHH, in both high- and low-predictability contexts. In contrast, first-grade CNH and CHH performed equivalently, regardless of contextual cues. The current results suggest that the development of fine-grained word recognition processes occurs sooner in CNH than CHH, resulting in a gap in speech recognition performance between the groups that does not appear until mid-elementary school. Even the presence of supportive contextual cues does not appear to completely eliminate this gap, as indicated in the trivariate model. These results offer a nuanced perspective on how auditory access, age, and predictability influence one another in support of spoken word recognition.

The results for the third graders were consistent with other studies that have shown that children with HL perform worse on speech recognition tasks than CNH (Blamey et al., 2001; Conway, Deocampo, Walk, Anaya, & Pisoni, 2014; Stelmachowicz et al., 2000). On the other hand, the results at first grade were surprising. We expected CHH to perform worse than CNH at both ages due to their

reduced auditory access. Instead, CHH and CNH performed similarly at first grade. The lexical restructuring hypothesis (Walley, 1993) may provide clarification for the significant interaction between age and auditory access. This hypothesis states that typically developing children shift from processing words as more global lexical items to more detailed phonological structures, as their vocabulary size grows and their experience with different words increases. This shift is demonstrated in earlier word recognition in gating tasks for 11-year-olds compared to 7-year-olds (Metsala, 1997). Consistent with Metsala's findings, CNH in the current study appeared to be processing speech in a more segmental manner in third grade compared to first grade. For the third-grade CHH, the later time to acceptance point in both high- and low-predictability contexts would suggest that they are less efficient in lexical processing because they require more acoustic-phonetic information to recognize the target word.

The slower performance in the third-grade CHH (relative to their NH peers) has potentially important clinical implications for later outcomes in children with HL. Experiencing a protracted period of reduced phonological sensitivity may slow down lexical processing because the majority of the acoustic-phonetic content of the word needs to be perceived before it can be recognized (Metsala, 1997). Inefficient word processing can manifest as deficits in online sentence comprehension in adolescence (Borovsky et al., 2013). In addition, weak lexical representations are associated with word learning and reading difficulties (Snowling et al., 1986; Wagner & Torgesen, 1987). Finally, a decreased sensitivity to fine-grained phonological structure within words may delay development of verbal working memory abilities (Nitttrouer et al., 2017; Nitttrouer, Caldwell-Tarr, & Lowenstein, 2013). Unfortunately, prospective research on language, reading, and memory skills for the current generation of adolescents with mild to severe HL is virtually nonexistent, so we can only speculate on the possible downstream effects of these findings. It is also unclear from the current data whether CHH older than third grade will continue to require more acoustic-phonetic information to recognize words or whether they will eventually catch up to their same-age peers. Further research into adolescence is needed to fully understand the trajectory of lexical processing in CHH.

Our second objective was to explore the underlying mechanisms for individual differences in word recognition in CHH, which could arise from multiple sources: (a) degraded and inconsistent auditory access, which impairs the ability to perceive phonological and lexical input; (b) delayed vocabulary growth, which reduces the need to develop more mature representations; or (c) reduced working memory capacity, which makes it more difficult to encode and maintain incoming information. These associations were explored via a mediation model to establish direct and indirect roles of independent variables on the dependent variable. The results support our prediction that performance on the gating task was supported by the combination of auditory access

and vocabulary (with vocabulary acting as a mediating factor) but was inconsistent with our prediction that working memory would also play a role.

Consistent with past studies, we found that children with higher aided audibility showed better word recognition (McCreery, Walker, Spratford, Oleson, et al., 2015), higher aided audibility was associated with better vocabulary (Stiles et al., 2012; Tomblin et al., 2015), and larger vocabulary size was linked to earlier word recognition (Elliott, Scholl, Grant, & Hammer, 1990). When these latter two correlations were controlled for in the mediation analysis, the association between aided audibility and gating performance was no longer significant. This finding provides insight into how auditory access affects word recognition. For CHH, lower level auditory access is critical, but its effect may be indirect when vocabulary size is taken into account. We may conclude that consistent auditory access is essential for developing strong vocabulary skills, and vocabulary development appears to play a powerful role in sensitivity to fine-grained phonological structure, as suggested by other researchers (Charles-Luce & Luce, 1995; Lowenstein & Nitttrouer, 2007; Metsala, 1997; Storkel, 2002). Clinical intervention for children with mild-to-severe HL should focus on ensuring access to spoken language through consistent use of appropriately fit HAs, but there should also be an emphasis on developing breadth and depth of vocabulary knowledge.

In contrast to the mediation analysis with vocabulary, we did not find a significant role for working memory in the gating task. The Ease of Language Understanding model proposes that, in the presence of adverse listening conditions, cognitive skills such as working memory facilitate word recognition (Akeroyd, 2008; Rönnerberg, Rudner, Foo, & Lunner, 2008; Rönnerberg, Rudner, Lunner, & Zekveld, 2010). Most of the research in support of the Ease of Language Understanding model has been conducted with adults, rather than children, and in the presence of background noise, instead of missing information. The findings that have been published on working memory and word recognition in children have been mixed, with some studies showing a correlation between working memory and word recognition (McCreery et al., 2017; Osman & Sullivan, 2014; Sullivan, Osman, & Schafer, 2015) and others indicating a dissociation between working memory and word recognition (Magimairaj et al., 2018). Our findings are consistent with Magimairaj et al., but there are several alternative explanations for the lack of a relationship between working memory and word recognition in the current study. One explanation is that we used a visual-spatial complex working memory task, rather than a phonological short-term memory task (e.g., nonword repetition) or a verbal complex working memory task (e.g., competing language processing task). Our rationale for using the visual-spatial task was that we wanted to reduce the verbal load of the memory measure and avoid shared variance with linguistic ability. Thus, while the results appear to indicate that variation in general working memory skills does not account for individual differences on the gating task, we

cannot exclude the possibility that verbal short-term or working memory contributes to performance. Future studies should look specifically at the role of verbal working memory while controlling for language ability or include a composite verbal and visual-spatial working memory score as the independent variable. Other possible explanations for the lack of significant findings are that the gating task does not create enough distortion in the input to require individuals to deploy working memory resources compared to other means of signal degradation, specifically background noise or reverberation, or the sentences simply were not long or grammatically complex enough to tax working memory capacity.

It is interesting to note that aided audibility was significantly correlated with visual-spatial complex working memory (Path A in the mediation analysis) for CHH. Although there is prior evidence to support significant associations between verbal working memory and aided audibility or PTA (Stiles et al., 2012), there is less evidence for a relationship between visual-spatial working memory and auditory access in CHH. Children who are deaf and use CIs have shown deficits in visual-spatial working memory (AuBuchon, Pisoni, & Kronenberger, 2015), leading some researchers to conclude that experiencing periods of auditory or linguistic deprivation in early childhood can have an impact on domain-general learning and memory skills (Deocampo, Smith, Kronenberger, Pisoni, & Conway, 2018). To our knowledge, this is one of the first studies to demonstrate a link between aided audibility and visual-spatial working memory in CHH with varying degrees of auditory access. We hypothesize that this relationship may arise from difficulties with using verbal encoding strategies and verbal rehearsal in a nonverbal task, as suggested by AuBuchon et al. (2015). However, we acknowledge that this hypothesis is highly speculative, and further research is needed to understand the mechanisms that underlie the association between nonverbal domains of working memory and variations in auditory access.

With respect to the CNH, we did not find an association between vocabulary or working memory on the gating task. The working memory findings are consistent with those of Evans et al. (2018), who did not find a significant correlation between working memory and word recognition on a gating task for 7- to 11-year-old typically developing children. However, these authors reported that receptive vocabulary was a significant predictor of speed of word recognition for the same group of children, in contrast to the current findings. Evans et al. tested 117 typically developing children, compared to 30 children in the current study. Thus, it is possible that we were underpowered and lacked sufficient variance in vocabulary size to find a significant association between vocabulary and gating performance in the NH group.

Limitations and Future Directions

This study had several limitations that should be acknowledged. One limitation is the cross-sectional design

of the study. Based on the existing data, we cannot confirm whether CHH fall behind CNH over the course of development or whether undocumented group differences between the first- and third-grade CHH accounted for the significant interactions between age and hearing status. An important future direction would be to examine performance on the gating task using a longitudinal design.

Although the gating paradigm offers a greater degree of experimental control compared to word or sentence recognition measures, there are still inherent limitations with the task itself (Allopenna et al., 1998; Montgomery, 1999; Patro & Mendel, 2018). Similar to most outcome measures used in research on children with HL, the gating paradigm is an end-point production measure. As Montgomery (1999) points out, performance on the gating paradigm may be more of a reflection of metalinguistic skills than real-time spoken word recognition. Allopenna et al. (1998) have also noted that the gating paradigm emphasizes word-initial information, thus activating cohorts (i.e., competitors that share initial segments with the target) but not rhymes (i.e., competitors that share word-final segments). Therefore, the gating paradigm is restricted in that it does not allow us to make substantive claims about the dynamics of online processing, such as lexical activation and competition. Research paradigms that better capture lexical-semantic activation would complement the findings of the current study and help to fill in the gaps of our knowledge regarding underlying mechanisms of word recognition in CHH (Nation, 2014). For example, the visual world paradigm via eye-tracking technology has revealed that adolescents and adults with CIs are slower to suppress lexical competitors during speech recognition (Farris-Trimble, McMurray, Cigrand, & Tomblin, 2014; McMurray, Farris-Trimble, & Rigler, 2017). Similar research has not been conducted with CHH, who experience inconsistent auditory access (Tomblin et al., 2015) and are learning language via a moderately degraded signal, relative to CIs. Strong and automatic lexical-semantic activation is an important foundational skill that supports higher level language comprehension and merits further investigation. Future studies using online lexical processing tasks are needed to fully understand the mechanisms that underlie possible delays in developing robust lexical representations.

A third limitation is that we only included measures of aided audibility, vocabulary, and complex working memory span as predictors of gating performance. It is also possible that attention skills impacted performance. Evans et al. (2018) found that attention switching and inhibition were significant predictors of acceptance point on a gating paradigm for children with developmental language disorders. There is some evidence that CHH have poorer executive function skills than CNH (Briscoe, Bishop, & Norbury, 2001; Willis, Goldbart, & Stansfield, 2014), but there is also evidence to the contrary (Stiles et al., 2012). Future research directions could involve examining how inhibition/selective attention and cognitive flexibility impact spoken word recognition in CHH.

Clinical Implications

This study focused on children with bilateral mild–severe HL. This population is often underrepresented in the research literature, despite representing a majority of the overall population of children with HL. Recent findings suggest that this population is at risk for communication delays, even when HL is “only” in the mild range (Tomblin et al., 2015; Tomblin, Oleson, Ambrose, Walker, & Moeller, 2018; Walker et al., 2015). Nevertheless, the intervention needs of CHH are sometimes overlooked in the educational setting (Antia, Jones, Reed, & Kreimeyer, 2009), and speech-language pathologists may lack pre-professional or professional preparation for working with school-age CHH (Page et al., 2018). Therefore, evidence-based research on factors that support listening and learning for CHH is critically important for developing effective clinical interventions. In the current study, we found that CHH are able to benefit from and use sentence context when perceiving speech. This knowledge may be especially useful for designing interventions to support CHH who must listen and learn in noisy classrooms. The provision of contextual information about a topic before teaching a lesson may positively influence speech understanding. In the absence of contextual information, children with HL may miss a substantial amount of spoken information from both their teachers and peers, particularly in later grades as the classroom learning environment becomes more formal and decontextualized. Furthermore, interventions that focus on vocabulary, such as preteaching vocabulary relevant to an upcoming lesson, may further enhance speech understanding in CHH in environments with suboptimal acoustics.

The clinical implications of these findings should also be viewed in light of the vocabulary standard scores in the group of children with mild–severe HL; the mean standard score was 107, and all 40 of the CHH scored within 1 *SD* of the PPVT-4 normative mean. The fact that vocabulary was a mediating variable for word recognition in children with vocabulary scores within the normal range suggests that clinical intervention targeting vocabulary may support spoken language processing in children with HL, even in cases where performance on standardized receptive vocabulary tests may not be indicative of a need for intervention in the area of lexical–semantic knowledge.

Conclusions

Results from a time-gated word recognition task indicated that differences in the amount of auditory information required for word recognition between CNH and CHH depend on age. A gap in word recognition performance appears between CHH and CNH during the time between first and third grades, with third-grade CHH demonstrating slower word recognition compared to third-grade CNH. Both CHH and CNH benefited from the addition of semantic information in sentence-level stimuli. Third-grade CNH were better able to take advantage of this semantic context compared to third-grade CHH, whereas

first-grade CHH and CNH showed similar levels of performance. The current study also sheds light on how vocabulary knowledge and auditory access support performance, in that larger vocabulary size was significantly associated with earlier word recognition in the CHH, and aided audibility had an indirect effect on performance. Interventions that focus on vocabulary may enhance the ability to fill in gaps in incoming messages, particularly for children with reduced access to the speech spectrum.

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Appendix

Low- and High-Predictability SPIN Sentences

High predictability	Low predictability
1. We shipped the furniture by the truck.	1. He knew about the brick.
2. He rode off in a cloud of dust.	2. He remembered the bridge.
3. Spread some butter on your bread.	3. Grace talked about the clock.
4. The baby slept in the crib.	4. She talked about the goose.
5. Abby took a bath in the tub.	5. She thought about the sun.
6. The boy gave the football a kick.	6. He thought about the kit.
7. Playing checkers can be fun.	7. Emma thought about the drain.
8. At breakfast he drank some juice.	8. She talked about the spice.
9. Get the bread and cut me a slice.	9. He knew about the flash.
10. The mouse was caught in the trap.	10. They remembered the yard.
11. At the beach we play in the sand.	11. They knew about the dance.
12. The guilty one should take the blame.	12. They knew about the cub.
13. The cow was milked in the barn.	13. She thought about the dart.
14. Tree trunks are covered with bark.	14. She talked about the track.