Auditory Lexical Decision and Repetition in Children: Effects of Acoustic and Lexical Constraints

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Objectives: The objective of this study was to identify factors that may detract from children’s ability to identify words they do and do not know. Factors investigated were acoustic constraints stemming from the presence of hearing loss (HL) or an acoustic competitor, and lexical constraints due to an impoverished or cluttered vocabulary.

Design: Eleven children with normal hearing (NH) and 11 children with bilateral, mild to moderately severe sensorineural HL were asked to categorize and repeat two-syllable real and nonsense words. Stimuli were amplified and frequency shaped for each child with HL and presented randomly at a level consistent with average conversational speech (65 dB SPL). About half of the children in each group listened in quiet while the other half listened in multitalker babble. In addition to overall performance, responses were judged based on the word category chosen by the child (real or nonsense), the category of the word produced by the child as judged by an examiner (real or nonsense), and the accuracy of the verbal response compared with the stimulus. From these judgments, 10 discrete types of errors were identified. Analyses were conducted for three different combinations of the 10 error categories to best characterize the effects of acoustic and lexical constraints.

Results: Performance was highest for real words presented in quiet and poorest for nonsense words presented in multitalker babble. Also, the performance of the children with HL was poorer than that of the children with NH. Error analyses revealed strong effects of acoustic constraints on performance but few effects of lexical constraints. The two most frequently occurring errors were the same for both children with NH and the children with HL and entailed the misperception of nonsense words and the mistaking of nonsense words for real words. However, while both groups of children exhibited these errors in multitalker babble, the children with HL demonstrated these errors in quiet as well.

Conclusions: These results suggest that children’s interactions with real and nonsense words are significantly constrained when the acoustic signal is degraded by HL and/or an acoustic competitor. The children’s tendency to repair unknown words into real words in the presence of acoustic interference may be beneficial when perceiving familiar speech, but could also be detrimental if that tendency causes them to miss opportunities to learn new words.

Key words: Children, Hearing loss, Nonword detection, Word learning.

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INTRODUCTION

The early identification of, and intervention for, hearing loss (HL) in infants has significantly improved young children’s potential for successful educational and communication outcomes (Moeller et al. 2007c). Early-identified infants and young children with HL are now more likely to achieve age-appropriate speech and language skills by the time they enter kindergarten (Yoshinaga-Itano et al. 1998; Moeller 2000; Moeller et al. 2007a, 2007b). There is evidence, however, that children with HL would benefit from continued support during the grade school and adolescent years to maintain age-appropriate academic and social skills consistent with their peers. Longitudinal, prospective studies of children identified through universal newborn hearing screening have not only confirmed the value of early identification but also highlighted some of the specific challenges that HL places on communication in academic and social settings. Several studies in the United Kingdom have identified long-term deficits in receptive language skills, expressive narrative content and structure, and reading comprehension (Kennedy et al. 2005; Worsfold et al. 2010; Pimperton & Kennedy 2012; Pimperton et al. 2014). Indeed, recent work from the Neonatal Hearing Outcomes Project in the United Kingdom revealed that the language deficits of grade-school children with moderate to profound HL tended to result in more behavioral problems than in children with normal hearing (NH; Stevenson et al. 2010). Specifically, children with poorer language skills demonstrated significantly higher levels of misbehavior despite receiving appropriate audiological intervention for HL (e.g., amplification, services in school).

In addition to grammatical and pragmatic skills, successful communication begins with a vocabulary that is both broad (defined by the number of known words) and deep (how well the words are understood; Nation 2014). Such a vocabulary provides the necessary foundation for children to communicate effectively, read comprehensively, and write meaningfully. For children and adolescents with HL, however, the depth and breadth of the vocabulary is significantly reduced. For example, the vocabularies of 8- to 12-year-old children with mild to moderate HLs are, on average, 2 years behind that of children with NH (Pittman et al. 2005).

The situation is more serious for children with severe to profound HL in that the disparity in vocabulary knowledge between NH and HL groups is closer to 4 years and increases with age (Blamey et al. 2001). In a study of postsecondary (i.e., college) students, Sarchet et al. (2014) found that not only did vocabulary knowledge in students with moderate to profound HL continue to lag behind that of students with NH the students with HL significantly overestimated their vocabulary knowledge. That is, they thought they knew the meaning of more words than they actually did.

Taken together, the existing literature suggests that poor vocabulary acquisition due to HL is a persistent problem for children. The goal of the present study was to examine the first step in the process of acquiring new vocabulary using an auditory lexical decision task. A model of word recognition and learning is introduced and form the basis of this exploratory study. The results were examined to determine the degree to which lexical and acoustic constraints influence children’s ability to detect words that they do and do not know. Significant constraints would suggest that they may miss opportunities to learn new words and to reinforce known words.
Toward a Model of Word Recognition and Learning

Most studies of word learning utilize the model of working memory put forward by Baddeley (2003). These studies have found that, in general, word learning difficulties in children with HL appear to be due to poor short-term memory (Willis et al. 2014) although there is some evidence to the contrary (Hanson et al. 2004; Stiles et al. 2012b). Because short-term memory likely involves a number of processes supporting the learning of new words as well as the recognition of familiar ones, it might be useful to combine models of word recognition and learning. One such example of complementary models is shown in Figure 1. The shaded boxes are the neighborhood activation model (Luce 1986; Luce & Pisoni 1998) and the open box is an emerging model of word learning gleaned from contributions of several researchers (Leach & Samuel 2007; Hoover et al. 2010; Gray et al. 2014). The neighborhood activation model represents the processes involved in recognition of familiar words. Specifically, speech input activates acoustic–phonetic pattern recognition which is then processed at the level of the lexicon for identification. Higher level lexical information contributes to identification of known words and results in recognition. In this model, the acoustic/phonetic similarities across words form lexical neighborhoods that can facilitate or impede recognition of certain words. For example, a simple word like “cat” has many lexical neighbors that differ by only one phoneme and may therefore be easily confused with other tokens under less than ideal listening conditions (e.g., fat, hat, bat, mat, cab, can). A word like “garden” on the other hand has few lexical neighbors (e.g., harden) and may be able to withstand some signal degradation.

But what if the word is not known (i.e., is new) to the listener? In this model, the detection of an unknown word begins a complementary process that promotes the integration of the new word into the lexicon. Specifically, when an unknown word is detected by the listener, a process of configuration is triggered. During configuration, input from the acoustic–phonetic pattern activation process as well as from the listener’s higher level lexical information is combined. These processes provide two important pieces of information: (1) the acoustic/phonetic content of the new word, and (2) a semantic interpretation of the new word based on the context in which it was perceived as well as similar items already residing in the lexicon. Engagement with the lexicon is considered to be an ongoing and reciprocal process that culminates in a representation of the word within the lexicon. Put simply, if a word is unknown to the listener, the acoustic and semantic characteristics of the word are gleaned from the input, linked together, and stored in the lexicon. This process is repeated each time the word is encountered until a stable acoustic and semantic representation within the lexicon has been achieved (Leach & Samuel 2007).

Research has shown that the neighborhood activation model predicts well the word recognition of adults and children with NH as well as adults and children with HL (Dirks et al. 2001a, b; Eisenberg et al. 2002; Takayanagi et al. 2002). Similarly, the word-learning model has been used effectively to understand the learning characteristics of typically developing children as well as children with speech-language impairment and children with HL (Storkel & Lee 2011; Pittman & Schuetz 2013; Gray et al. 2014). By combining these models, recognition of known words as well as the cumulative learning of new words is captured. Also, the acoustic–phonetic pattern activation that occurs immediately upon stimulus input allows for more accurate predictions of the effects of acoustic constraints (e.g., HL, noise) on both word recognition and word learning. For example, it is possible that configuration of unfamiliar words is impaired by acoustic interference such that distorted representations of these words may be stored in the lexicon. It is even possible that multiple distorted tokens of the same word are stored but are considered to be unique items by the listener. For example, a child with HL may misperceive the word “spoon” as “poon” and store the misrepresentation in the lexicon as a reference to a unique type of utensil rather than a reference to all spoons. An equally serious problem is failure to trigger the learning process altogether when an unknown word is not detected because it is misperceived as an already known word. For example, a child may misperceive the phrase “That was a lot.” as “That was a lot.” Over time, these missed or failed opportunities for learning new words may result in a lexicon that is both impoverished of real words and cluttered by the accumulation of lexical debris.

Children’s Interaction with Nonsense Words

Nonsense word repetition has been shown to be poorer in grade-school children with mild–moderate HL compared with children with NH, especially as the words increase in syllable length (Briscoe et al. 2001; Dillon et al. 2004; Stiles et al. 2012a). However, two studies reported unexpected results. Willis et al. (2014) asked 8- to 15-year-old children with moderate to profound HL to repeat lists of single-syllable nonsense words followed by lists of single-syllable real words. The children used their personal hearing aids (n = 3) or cochlear implants (n = 3) during testing. Because the children with HL also had comorbid language delays (2 years), it was predicted that they would experience more difficulty holding the acoustic–phonetic representations of nonsense words in short-term memory compared with real words. Instead, the children with HL were able to repeat the lists of nonsense words better than the lists of real words. In fact, their nonsense word repetition was equal to that of normative data for children with NH (within 1 SD above the standard score). However, because the children were informed of the category of the words to be repeated before each trial (i.e., real or nonsense), the authors speculated that perception...
and repetition of the nonsense words was easier since there was no need to reconcile these words with items in their lexicons. With respect to the combined neighborhood activation and word learning models in Figure 1, repetition of real words activates higher level lexical information whereas that information is not necessary for the repetition of nonsense words. That is, because the children were told that the words were nonsense, there was no need to evaluate them against known words. It is possible then, that the children’s poorer performance for real words was due to an inability to recognize the words that they were expected to know.

Pittman and Schuett (2013) reported a similar result when they asked grade-school children with and without HL to count the number of nonsense words embedded into four-word sentences. Words in the sentences were one-syllable each and the sentences contained zero, one, or two nonsense words. All other words were monosyllabic real words arranged to be grammatically and semantically correct. It was hypothesized that the children with HL would identify more nonsense words than were present in the sentences due to poor acoustic–phonetic pattern activation caused by HL. As expected, the children with HL did perform more poorly than the children with NH but not because they identified too many nonsense words. Instead, they identified too few nonsense words. Given that children with HL are able to perceive one-syllable nonsense words as accurately as children with NH (Willis et al. 2014), the most likely explanation is that they repaired the nonsense words to be real words to fit into the context of the sentence. For example, in the sentence “Cooks make hot foom,” the correct response is one nonsense word. But the sentence can be easily (and perhaps unconsciously) repaired to “Cooks make hot food.” based on the context. If this is the case, the children may be contending with irreconcilable strategies: one for perceiving words they already know and one for perceiving and learning words that they do not know. In this particular task, the children were told that nonsense words were embedded into the sentences and that their job was to listen for them. The task was specifically designed to focus on the nonsense words rather than on the real words. Their failure to recognize the nonsense words suggests that the strategy they use to perceive speech may compete with (and be counterproductive to) the strategy they use to learn new words.

**Purpose**

The purpose of the present study was to examine children’s ability to detect words that are and are not known to them. To do so, an auditory lexical decision and repetition task was created and included both real and nonsense words. The real words were drawn from the vocabularies of first graders and should be familiar to most children. The nonsense words were created and served as proxies for words that are unknown to children. For each word, two pieces of information were obtained from the listener: a verbal repetition of the word and a categorical decision about the word (real or nonsense). The results were interpreted in light of the combined neighborhood activation and word learning models to identify lexical and acoustic constraints on performance. Lexical constraints refer to distorted or missing representations of words within the lexicon, whereas acoustic constraints refer to degraded perception of known and unknown words either due to internal factors such as HL or external factors like an acoustic competitor in the listening environment (e.g., multitalker babble). Multitalker babble was included to create additional acoustic interference for the children with HL to determine if their errors increased or changed in nature. In addition to the expected effects of listening condition on overall performance (quiet > multitalker babble), word familiarity (real > nonsense), and hearing status (NH > HL), it was hypothesized that the children with HL would demonstrate more errors due to both acoustic and lexical constraints than the children with NH in both quiet and multitalker babble.

**MATERIALS AND METHODS**

**Participants**

A total of 22 children (ages 7–12 years) were recruited for this study. The control group consisted of 11 children with NH (4 boys, 7 girls) and the experimental group consisted of 11 children with permanent, mild to moderately severe HL (5 boys, 6 girls). The children were all mainstreamed at grade level and were native speakers of English. Of the children enrolled in the study, approximately half participated in the quiet listening condition (7 NH, 6 HL) and half participated in the multitalker babble condition (4 NH, 5 HL). On average, the children in the quiet condition differed in age by 2 years (NH: 10 years, HL: 12 years) as did the children participating in the multitalker babble condition (NH: 11 years, HL: 9 years). No child participated in both listening conditions. Group assignment was by convenience sampling due to the choice to include a multitalker babble condition after completion of data collection in quiet. The age, gender, and hearing thresholds of each child are provided in supplemental appendix A (http://links.lww.com/EANDH/A213) according to hearing group and listening condition.

On the day of testing, the children completed pure-tone threshold testing to determine their hearing sensitivity at octave frequencies between 0.25 and 8 kHz. Normal middle-ear status was confirmed by acoustic admittance measures for all but one ear. This child had NH thresholds bilaterally with a mild conductive loss <500 Hz in the left ear. Her performance on the experimental tasks was excellent (93%), thus she was not excluded from the study. Figure 2 shows the average hearing thresholds (±1 SD) for the right and left ears of the children with NH and the children with HL who participated in the quiet listening condition (upper panel) and in the multitalker babble condition (lower panel). On average, the children with NH had thresholds ≤15 dB HL, bilaterally. The children with HL had mild, sloping to moderate losses, with slightly poorer thresholds in the mid-frequencies in the children participating in the multitalker babble condition (5 to 10 dB). To accommodate the variability in hearing thresholds within and across groups, the stimuli were amplified and frequency shaped for each child individually according to standardized hearing aid fitting parameters (see below). All testing was conducted in a sound-treated booth meeting ANSI standards for room noise (American National Standards Institute 1999). Children were paid $15 per hour for participation. Testing required no more than a single, 2-hour session. Informed consent and assent were obtained for all participants according to the procedures approved by the Institutional Review Board at Arizona State University.
Stimuli

The stimuli were created by first compiling 144 nouns within the vocabulary of first-grade children (Moe et al. 1982). For each of these nouns, three nonsense words were created by replacing, deleting, or adding one or more phonemes in each word for a total of 432 words. For example, the word “movie” was modified by replacing the /m/ with an /s/ to form the nonsense word “soovie.” To adhere as closely as possible to the rules of English when creating the nonsense words, the phonotactic probability of each phoneme removed from a real word was calculated (both positional and biphone) and replaced with a phoneme having the same probability (Vitevitch et al. 1999; Vitevitch & Luce 2004). In this way, the nonsense words would be internally consistent with the real English words. The 432 nonsense words were then presented to a group of graduate students with NH who were asked to write the first real English word that came to mind for each. Nonsense words for which three or more listeners responded with the same English word were excluded. In this way, the words could be considered consistent with English but not so similar that confusion with the same English words would occur more frequently for some words than for others. Fifty of the remaining nonsense words were combined with 50 real words and divided equally into four lists of 25 words each. These are listed in supplemental appendix B (http://links.lww.com/EANDH/A214). Each list contained 12 to 13 real words and 12 to 13 nonsense words. The root words from which the nonsense words originated were not included in the same list, although some root words were included in other lists. Other than controlling for phonetic probability and word familiarity, no other attempts were made to control lexical neighborhood or neighborhood density.

For presentation to the children, the stimuli were recorded digitally and presented under earphones. The stimuli were spoken by a female talker with a standard American English dialect. Stress was placed on the first syllable of each two-syllable word. Recordings were made at a sampling rate of 22.05 kHz using a microphone with a flat frequency response to 10 kHz (AKG, C535EB). The words were edited using a digital audio editor (Adobe Audition) to equate them for root-mean-square level and to create single audio files of each word. All stimuli were routed binaurally through earphones having a flat frequency response to 10 kHz (Sennheiser, 25D). For the children with NH, the stimuli were presented at an overall level of 65 dB SPL, which is consistent with average conversational speech. To accommodate the elevated thresholds of each child with HL and to provide them with an equivalent listening experience, the stimuli were amplified and frequency shaped to be appropriate for average conversational speech according to the desired sensation level prescription procedure (DSL V5.0A; Scollie et al. 2005). The targets were derived using age-appropriate real-ear-to-coupler differences and a speech-weighted input level for conversational speech (65 dB SPL). Using this procedure, each child received the frequency shaping and sensation level appropriate for his/her HL. Because the stimuli were presented via supra-aural earphones, rather than insert phones, target levels were approximated by measuring the 1/3 octave bands levels developed in a 6-cm³ coupler.

Listening Conditions

All four-word lists (100 words total) were presented to each child in either a quiet listening condition or in multitalker babble. The children were given a short break between each list of 25 words. The multitalker babble was presented at a +3 dB signal to noise ratio and contained conversations of six men and six women recorded separately and then mixed together into a single audio file. Some semantic information was preserved, in that small portions of each conversation (a few words) could be followed selectively.

Procedure

The children’s task was to repeat aloud each word presented and then state whether the word was “real” or “not real.” These responses were recorded using a digital recorder with an omnidirectional lapel microphone (RadioShack, Model #33–3013) that was placed approximately 6 in from the child’s mouth. On each trial, a word was randomly selected by custom laboratory software and presented to the child. Although the temporal parameters of the experiment were controlled via the software, the children’s responses were self-paced. Feedback regarding the accuracy of the responses was not provided. All testing was conducted in a sound-treated booth. The following instructions were given to the child before beginning the task: “You are going to hear a list of words one word at a time. Some of them will be real and some of them will be nonsense. Your job is to listen and say each word out loud into the microphone. Then say whether the word you heard was “real” or “not real.” If you do
not know, it is okay to guess. Listen carefully because you will only hear each word one time.” Once the child was comfortable with the instructions and format, testing for the experimental conditions proceeded.

Data Reduction
The digital audio recordings of each child’s verbal repetitions were scored by an independent examiner (graduate research assistant with clinical experience) in two ways. First, the word produced was categorized as a real or a nonsense word regardless of the category of the stimulus or the accuracy of the response. Second, the word produced was compared with the stimulus and categorized as an accurate or inaccurate repetition. No consistent patterns of phonological errors were observed within or across the children’s responses (e.g., final consonant deletion, stopping). These assessments were combined with the child’s category selection to form three layers of response. The 12 possible response combinations (6 for each stimulus category) are displayed in Figure 3. The rows represent the category of the stimulus (fourth row) as well as each layer of response. Specifically, the third row represents the category of the word selected by the child (real, nonsense). The second row is the category of the word produced by the child as judged by the examiner (real, nonsense). The first row is the examiner’s judgment of the accuracy of the word produced relative to the stimulus (yes, no). Examples of each type of error relative to the stimulus are provided. Incorrect responses at each level are shaded gray, with completely correct responses located at the center of the continuum and completely incorrect responses located at each end. Instances of no response (i.e., the child failed to respond) are not shown in the figure. Because all responses were verbal, failure to respond included either repetition or categorization of the words.

Statistical Analyses
The proportion of trials in each of the response categories were arcsine transformed before statistical analyses to equalize the variance over the range of scores (Studebaker 1985). Analyses of variance were conducted to identify main effects and interactions between hearing groups (NH, HL) and listening conditions (quiet, babble). Age was entered into each analysis to control for the differences between groups. Also, the degrees of freedom were adjusted as necessary using the Greenhouse-Geisser method to accommodate any lack of sphericity in the variance over the range of scores (Studebaker 1985). Analyses of variance were conducted to identify main effects and interaction between hearing groups (NH, HL) and listening conditions (quiet, babble). Age was entered into each analysis to control for the differences between groups. Also, the degrees of freedom were adjusted as necessary using the Greenhouse-Geisser method to accommodate any lack of sphericity in the data. Significance was indicated by \( p < 0.05 \). Confidence intervals for multiple comparisons were adjusted using the Bonferroni method. Overall correct performance for each group and listening condition was evaluated first, followed by analyses of individual and combined error categories.

<table>
<thead>
<tr>
<th>Accurate Repetition</th>
<th>No “cat”</th>
<th>No “glug”</th>
<th>Yes “cat”</th>
<th>Yes “glug”</th>
<th>No “cat”</th>
<th>No “glug”</th>
<th>Yes “cat”</th>
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<td>Response Category</td>
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<td>Stimulus</td>
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<td>nonsense word “glug”</td>
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Fig. 3. Chart showing the 12 possible response categories for the real and nonsense stimuli. The shaded boxes represent incorrect responses.

RESULTS

Figure 4 shows the average performance in proportion correct (+1 SE) as a function of hearing group for the quiet (dark bars) and babble (light bars) listening conditions. The results represent completely correct responses in both category and repetition accuracy. The remaining 10 error categories are not shown. As expected, the performance of the children in the quiet condition was better than that of the children in the multitalker babble condition \( F(1,22) = 10.104, p = 0.005, \eta^2 = 0.373 \). Also, the performance of the children with NH was higher than that of the children with HL \( F(1,22) = 31.99, p < 0.001, \eta^2 = 0.653 \). However, no hearing status × listening condition interaction was revealed \( F(1,22) = 0.245, p = 0.627, \eta^2 = 0.014 \) indicating that performance in babble decreased similarly for both children with NH and children with HL.

Error Analyses

The remaining analyses focused on the nature of the children’s errors. First, the proportion of errors due to no response was calculated for each group and listening condition. Overall, the no response rate was very low for all groups (<2%) with the exception of the children with HL in the multitalker babble condition (13%). These differences, however, failed to reach statistical significance for main effects of group \( F(1,22) = 0.765, p = 0.394, \eta^2 = 0.043 \) or listening condition \( F(1,22) = 0.619, p = 0.442, \eta^2 = 0.035 \). No group × listening condition interaction was found \( F(1,22) = 0.294, p = 0.595, \eta^2 = 0.014 \). These results indicate that although the no-response rate of the children with HL was higher in multitalker babble, the variability across children was sufficient to obscure any differences between groups and listening conditions.

Next, the proportion of errors for each response combination (as shown in Fig. 3) was determined. Figure 5 shows the average proportion of errors (+1 SE) as a function of each response combination, hereafter referred to as category, for the quiet (upper) and babble (lower) listening conditions. The light and dark bars represent the children with NH and the children with HL, respectively. The bars are aligned vertically with the graph to show the combination of responses associated with each category which are numbered for ease of reference. Not shown are the two categories of completely accurate responses. Overall, the children with HL made more errors in both listening conditions than the children with NH. The children with NH made few errors in quiet but more errors...
in babble. Repeated measures ANOVA confirmed a significant main effect of hearing status \([F(1,17) = 22.04, p < 0.001, \eta^2 = 0.565]\) as well as a significant category \(\times\) hearing status interaction \([F(9,153) = 11.88, p < 0.001, \eta^2 = 0.411]\). These results indicate that the children with HL made more errors overall and that the distribution of those errors across categories differed from that of the children with NH. Also, a significant category \(\times\) listening condition interaction \([F(2.224,37.809) = 4.152, p = 0.02, \eta^2 = 0.196]\) indicates that the distribution of errors differed across categories in babble compared with quiet. The three-way interaction of category \(\times\) listening condition \(\times\) hearing status interaction was not significant \([F(9,153) = 1.06, p = 0.399, \eta^2 = 0.058]\). The errors of both groups were mostly limited to two categories involving nonsense words (#6 and #10). Post hoc pairwise comparisons (Bonferroni method) revealed similar error rates for these categories and that these errors were significantly greater than for all other categories. The results suggest that when perception is impaired by HL or an acoustic competitor, children are less able to repeat nonsense words accurately (#6) and they fail to recognize nonsense words altogether such that they mistake them for real words (#10). Also, the results suggest that the number of errors made by the children with HL did not increase in babble as they did for the children with NH.

### Response Certainty/Uncertainty

Because many of the response combinations share common features, they were regrouped to form three new categories. These new categories are shown in Figure 6 using the same convention as in Figure 5. Misperception comprised two error categories representing responses that were closest to correct whereas Misconception comprised two error categories representing completely inaccurate responses. Although these categories are on opposite ends of the same continuum of accuracy, they both represent high levels of response certainty due to the internal consistency of each level of response. The ambiguous category, on the other hand, comprised six error categories having one or two aspects of the response that were correct while one or two were not. This category can represent a number of different response processes (including uncertainty) causing errors at different levels of the response.

Overall, the children with NH made few errors with the exception of misconception in babble. This suggests that the children with NH were fairly confident in what they perceived even though their responses were inaccurate. The error pattern of the children with HL, on the other hand, was similar in both quiet and babble. Like the children with NH, most of their errors were consistent with response certainty (misperception and misconception), whereas ambiguous responses accounted for the fewest errors. Repeated measures ANOVA confirmed the main effects of hearing status \([F(1,17) = 21.964, p < 0.001, \eta^2 = 0.564]\) as well as an error category \(\times\) hearing status interaction \([F(2,34) = 8.385, p = 0.001, \eta^2 = 0.330]\), suggesting that the configuration of errors differed across hearing groups. Likewise, a significant error category \(\times\) listening condition interaction \([F(2,34) = 4.906, p = 0.013, \eta^2 = 0.224]\) indicates that the configuration of errors differed across listening conditions as well. Finally, pairwise comparisons (Bonferroni method) revealed equal frequency of misperception and misconception errors (four categories), while ambiguous errors (six categories) occurred significantly less often. These results suggest that most of the children’s errors were not due to ambiguous response combinations but rather to minor errors in perception or to completely inaccurate conception of the stimuli. That is, most errors were nearly correct, or completely incorrect, response combinations.

![Fig. 5. Average proportion of errors (+1 SE) as a function of 10 error categories for the quiet (upper panel) and multitalker babble (lower panel) listening conditions.](image)

![Fig. 6. Average proportion of errors (+1 SE) as a function of the original 10 error categories condensed into three categories representing certainty/uncertainty of the responses.](image)
Acoustic and Lexical Factors

In the final analysis, the categories were regrouped once again to reveal acoustic or lexical constraints that may have influenced the children’s responses. These are shown in the table below the graph in Figure 7. Categories consistent with lexical constraints represented errors due to inadequate or inaccurate representations of items in the lexicon. For example, categories two and three represent real words that were considered to be unknown and therefore categorized as nonsense. Likewise categories eight and nine were nonsense words that were thought to be real. Categories consistent with acoustic constraints were those for which the selected and response categories were the same. For example, categories one and ten represent errors at every level of response, whereas categories five and six are errors of repetition only. Each of these errors is consistent with misperception of the stimulus although to different degrees. Two categories (four and seven) were not included because these responses may stem from more than one type of error. For example, category seven represents errors in which the child heard a nonsense word, indicated that the word was nonsense, but produced a real word. This error may be due to (1) repair of a nonsense word into a real word by the examiner, (2) a real word that was unknown to the child, or (3) miscategorization of the word.

Figure 7 shows the average errors (+1 SE) of the combined lexical and acoustic constraints as a function of group. The results for the quiet and babble listening conditions are shown in the upper and lower panels, respectively. The shaded sections of each bar are described below. Repeated measures ANOVA confirmed the main effect of hearing group \[F(1,17) = 20.38, \ p < 0.001, \ \eta^2 = 0.545\] and listening condition \[F(1,17) = 6.177, \ p = 0.024, \ \eta^2 = 0.267\]. The significant constraint × hearing group \[F(1,17) = 16.886, \ p = 0.001, \ \eta^2 = 0.498\] and constraint × listening condition \[F(1,17) = 9.247, \ p = 0.007, \ \eta^2 = 0.352\] interactions indicate that most of the errors were due to acoustic constraints, particularly for the children with HL in the babble condition.

Finally, the lexical and acoustic errors were examined further to determine whether they might reveal specific characteristics about the source of the errors. For the lexical errors, categories eight and nine represent lexical omissions in which real words were considered to be nonsense even though the children repeated real words in response. For the acoustic errors, categories five and six represent simple misperception due to incorrect repetition. That is, the child’s selections were within the correct category but their repetitions were incorrect. Category ten represents repair in which the child perceived and produced real words in response to nonsense words. Finally, category one represents misconception in which the child’s response to real words was completely inaccurate. The error characteristics are shown in Figure 7 as shaded sections according to the descriptors given above. The figure shows that, of the few lexically-based errors, most were due to lexical surplus, suggesting that the vocabularies of children with HL may contain some ambiguous items. For the acoustically-based errors, most were due to simple misperception of real words and to the repair of nonsense words. Very few errors were due to the complete misconception of real words. Repeated measures ANOVA revealed a significant category × hearing status interaction \[F(1.862,31.654) = 16.661, \ p < 0.001, \ \eta^2 = 0.495\] as well as an error category × listening condition interaction \[F(1.862,31.654) = 4.803, \ p = 0.017, \ \eta^2 = 0.220\]. Pairwise comparisons (Bonferroni method) revealed that similar proportions of errors due to lexical surplus (eight and nine) and omission (two and three) occurred. Also, the overall frequency of errors due to misperception (five and six) and repair (ten) was the same and occurred significantly more often than errors due to misconception (one). These results suggest that although most errors were due to acoustic factors, the children’s responses indicate that they were as likely to repair nonsense words into real words as they were to misperceive real or nonsense words.

DISCUSSION

Recall that the purpose of the present study was to examine acoustic and lexical factors that may affect children’s ability to detect words that they do and do not know. Because all words are equivalent to nonsense words before they are learned, nonsense words were included in the paradigm as proxies for new words. The children repeated the real and nonsense words and then categorized each as being either real or nonsense. Their responses were evaluated according to the accuracy of the chosen category as well as aspects of their verbal repetition. As hypothesized, performance was better for children with NH, highest for real words in quiet, and poorest for nonsense words in babble. Also, error analyses indicated that acoustic constraints due to HL or multtalker babble accounted for most of the errors while lexical constraints associated with poor or inadequate representations of items within the lexicon accounted for very few errors.
Because the errors of the children with NH are, by definition, normal, their performance provided a reference with which to parse the recognition of known words and the processing of unknown words as illustrated in the combined neighborhood activation and word learning models. The results indicate that identifying known and unknown words is relatively easy for children with NH, especially in quiet. This suggests that the acoustic/phonetic pattern activation and higher level lexical information was sufficiently represented to identify and repeat both real and nonsense words accurately. However, performance for nonsense words decreased with the addition of an acoustic competitor (multitalker babble) suggesting that acoustic/phonetic pattern activation plays a significant role in nonsense word identification and that higher level lexical information was unable to compensate during lexical processing. Indeed, the two most commonly occurring errors in multitalker babble represent two different types of lexical processing errors resulting from poor acoustic representation of the stimuli. One error appeared to be simple misperception, in which the children were able to identify the words as nonsense but were unable to repeat them accurately. The other error suggests that the children’s perception of the nonsense words was so poor the higher level lexical information took over and provided real words instead (repair). Although the first error may cause children to misperceive nonsense words, the second error may represent missed opportunities to learn new words.

The children with HL demonstrated the same distribution of errors as the children with NH but with two important differences. First, unlike the children with NH, these errors occurred in quiet as well as in babble, suggesting that HL promotes persistent errors of misperception and repair in children. Second, the effects of HL and multitalker babble were not additive. This is inconsistent with the results of studies like that of Finitzo-Hieber and Tillman (1978) and others, and may be due to the fact that two different groups of children with HL participated in the quiet and babble conditions. Thus, the additivity of the two sources of acoustic interference is not entirely clear. However, because the children with HL in the multitalker babble condition were younger and had more HL than those who participated in quiet, one would expect that they would make more errors overall or that the variability in their performance would be greater, but this was not the case. In fact, the lack of a significant difference between the errors in quiet and in multitalker babble strengthens the interpretation that these errors are prevalent across all children with HL.

Effects of Identification Errors on Lexical Status

The two most common errors, misperception and repair, may affect a child’s lexicon in specific ways. Misperception of new words may lead to lexical surplus if the misperceived words are integrated into the child’s lexicon. Although more children with HL demonstrated errors associated with lexical surplus, these comprised very few of the errors overall (<5%). Thus, it is possible that lexical surplus is a temporary problem that is remediated with repeated exposures to new words during the learning process. If so, the veracity and time course of this possibility may be an important question for further research given that HL predisposes children to fewer exposures to new words overall.

Of equal concern is the tendency for children to repair unknown words into real words. Although some repair appears to be normal, particularly in noise, consistent repair as in the case of children with HL may result in missed opportunities to learn new words or fortify recently acquired words in the lexicon. Children’s strategy for repairing unknown words may be the result of coping strategies used when attempting to communicate in adverse listening situations. That is, children may learn to prioritize speech perception over word learning and thus apply repair strategies so that they are more likely to communicate successfully in noise. Such strategies may explain, in part, the smaller vocabularies of children with HL compared with children with NH (Blamey et al. 2001; Pittman et al. 2005). This, too, is a matter for further research to determine the impact that such repair might have on children with HL and, more importantly, solutions for these children that will allow them to continue to prioritize successful communication while optimizing learning. Interestingly, Sarchet et al. (2014) argue that the impoverished vocabularies of postsecondary students with HL are a reflection of their limited world knowledge and do not appear to be aided by print exposure or to comprehension monitoring. If so, the importance of incidental learning through optimal access to the acoustics of speech at home and at school cannot be overemphasized (Akhtar et al. 2001; Akhtar 2005).

Another avenue for further research is to relate children’s errors to other measures of auditory and cognitive function (e.g., receptive/expressive vocabulary, hearing level, working memory capacity, etc.). Merriman et al. (2008) examined something similar in young children’s semantic retrieval relative to their working memory capacity. They wanted to know if young children judge the familiarity of a word on the basis of acoustic information (i.e., sound of the word) or on the available semantic information (i.e., meaning of the word). Their results were generally consistent with the hypothesis that the children’s approach was related to their working memory capacity. Unfortunately, their tasks were somewhat difficult and many of the children could not complete them all. Thus, it was not possible to draw strong conclusions from their results. It would be interesting to know if children’s tendency to misperceive or repair nonsense words is related to their working memory capacity or to the breadth and depth of their receptive vocabulary.

Important Considerations

This study differs from other studies involving nonsense word repetition in children with HL in at least one important respect. Most studies aim to identify possible markers for language or learning impairment in children by examining their working memory capacity and/or phonological processing capability (Briscoe et al. 2001; Dillon et al. 2004; Stiles et al. 2012a, 2012b, 2013). Poor nonsense word repetition is thought to be a product of a child’s inability to hold all of the phonemic pieces of the word in working memory. Such studies involve standardized tests of nonsense word repetition for adults (Dollaghan & Campbell 1998) or for children (Gathercole et al. 1994) which contain stimuli that range from two to five syllables. The stimuli in the present study, as well as those of Willis et al. (2014) and Pittman and Schuett (2013), were generally simpler, two-syllable nonsense words. Shorter stimuli were selected because they better represent the majority of words that children will learn during their grade-school years and allow for a closer approximation of the listening skills that
would be required of children. More importantly, these stimuli reveal the tendency for children with HL to repair nonsense words into real words which is unlikely to happen for words like “berrizen,” “comisitate,” or “detrapatilice” (Dillon et al. 2004) which have no close phonological or lexical neighbors. It should be noted, however, that the nonsense words in previous studies are lengthy by design. Such stimuli challenge working memory sufficiently to determine its capacity and relate that capacity to processes like word learning.

Other considerations in the present study include the small number of participants, the choice of stimuli, and the relation of these results to working memory and vocabulary measures. First, although significant differences were observed throughout many of the statistical analyses, several effects could not be established (e.g., differences between groups for some listening conditions and error categories, the frequency of occurrence of lexical surplus and omissions). Confirming the results of this study with a larger group of children having a range of hearing levels, working memory capacities and receptive vocabularies would be worth pursuing. Also, thoughtful consideration should be given to the stimuli in terms of lexical neighborhoods and frequency of occurrence. Adjustments to the stimuli may increase the sensitivity of the test further and be useful for predicting the types of words that children are likely to misperceive or repair.

One last and more perplexing consideration is that this paradigm does not reveal when a child correctly repairs a word that was perceived incorrectly. That is, it is not possible to determine when children misperceive real words but, due to their experience with their native language, they are able to correct their error to categorize and produce the word accurately. One possibility is to measure response time, assuming that such repair requires greater effort and time to access higher level lexical information to find a word that has the highest probability of being correct. Longer response times may indicate that the correct response was the product of greater interaction with the lexicon, whereas shorter times may indicate that the word was easily identified.

CONCLUSIONS

Children’s ability to identify words that are known or unknown to them is influenced most by acoustic constraints rather than by the state of their lexicons. While the children with NH experienced the effects of acoustic constraints in multitalker babbles, the children with HL experienced similar and persistent effects of HL, even in quiet. Two specific types of errors (misperception and repair) appear to be most prevalent for both children with NH and children with HL, although to a greater extent in the presence of HL. These errors suggest that children with HL are vulnerable to the misperception of unknown words and to the repair of unknown words into real words which may cause them to miss opportunities to learn new words.

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