DOI: 10.61782/fa.2023.0406

FACTORS THAT UNDERLIE LISTENING EFFORT FOR CHILDREN WHO ARE HARD OF HEARING

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ABSTRACT

Many children with mild to severe hearing loss are identified and receive early intervention at very young ages. Even with this early intervention, however, children who are hard of hearing (CHH) experience challenges due to reduced auditory access. These challenges are further compounded because CHH have increased difficulty perceiving speech in adverse acoustic conditions and most listening conditions are characterized by poor acoustics. When listening in adverse conditions, CHH must exert additional cognitive resources to perceive an incoming message. Consequently, they have fewer cognitive resources available to perform additional tasks and must expend increased listening effort. The current paper will describe the factors that underlie increased listening effort in school-age children. Fifty-nine CHH were administered behavioral and subjective measures of listening effort. Stimuli were presented in different levels of background noise. As aided audibility levels increased, perceptions of listening effort decreased within CHH who used hearing aids. These findings suggest that amplification appears to ameliorate listening effort in children.

Keywords: *speech recognition, children, listening effort, language, attention***.**

1. INTRODUCTION

Hearing loss (HL) in childhood is a relatively common condition, experienced by 15% of children [1]. Children who are hard of hearing (CHH) are now being identified and fit with hearing aids (HAs) during infancy [2]. These service provisions are posited to have a positive, long-term impact on functional outcomes. Nevertheless, CHH are still at risk for developmental delays [3]. Until recently there were few studies that focused exclusively on children with bilateral, mild-to-severe HL. Consistent access to sound is critical for CHH to achieve age-appropriate language skills, which are essential for academic achievement. Historically, however, there is a lack of information on factors that are amenable to intervention (i.e., malleable factors), such as amount of access to the speech spectrum via HAs [4]. There is also a knowledge gap in how CHH manage listening demands in complex listening environments in CHH [5]. Acquiring such knowledge requires investigators to go beyond examining performance on traditional clinical measures (e.g., speech recognition). Although speech recognition tests are clinically useful, they are not sensitive to the cognitive demands of real-world listening, which requires multitasking and reliance on cognitive-linguistic skills. This is particularly true in school, where a student is expected not only to listen to a teacher's message in a degraded listening environment, but also to fully comprehend and integrate that message, while simultaneously performing other tasks (e.g., taking notes).

For CHH, there is evidence that multitasking situations are taxing due to the additional listening effort needed to understand speech [6]. However, we are limited in our understanding of the factors that are associated with listening effort. To identify these factors, we must utilize measures that are sensitive to both bottom-up and top-down processes required for recognizing speech. The dual-task paradigm is a quantitative objective measure to assess listening effort [7]. In this paradigm, an individual performs two tasks simultaneously. As the primary task increases in difficulty, decrements on the secondary task reflect increased effort. Subjective ratings of perceived listening effort are another approach that may be used in conjunction with objective measures [8 9]. CHH demonstrate individual differences in listening effort on both of these measures [6]. There is strong empirical support that cognitive skills in adults are associated with

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individual differences in listening effort [10]. Because CHH have limited access to the acoustic signal, it is plausible that better cognitive-linguistic skills will compensate for decreased audibility with this group, as it does with adults.

Our hypotheses were that lower levels of aided audibility would be associated with greater amounts of listening effort in CHH, and this relationship will be mediated by working memory and vocabulary skills. Furthermore, we predicted that the relationship between cognitive-linguistic skills and listening effort would be stronger for children who had poorer aided audibility, because they had to rely more on explicit cognitive-linguistic skills to compensate for their reduced access to sound. These hypotheses were tested by using aided audibility (measured with the Speech Intelligibility Index), vocabulary, and working memory as direct and indirect predictors of objective and subjective measures of listening effort.

In summary, there are gaps in our knowledge regarding factors that drive increased listening effort in CHH. It is critical to fill these gaps because mounting evidence suggests that listening effort puts CHH at high risk for fatigue [11 12], and fatigue is associated with decreased language skills in children with HL [13].

2. METHOD

2.1 Participants

The sample included 59 CHH recruited at the University of Iowa. All children used spoken English as their primary language and did not have a history of additional developmental disabilities. Table 1 shows descriptive statistics for the sample. Children were paid $15/hour for their time. Parents provided consent and children provided assent to participate in the study. The study was approved by the Institutional Review Board.

2.2 Materials

The speech recognition task included sentences from the Hearing in Noise Test (HINT; [14]), which is appropriate for children 8 to 12 years old [15]. The HINT consisted of one male talker with speech-shaped noise as the masker, with 24 lists and 10 sentences per list (no repetitions during testing).

2.3. Procedures

Parents completed an intake questionnaire on a tablet while the children completed the study visit. The questionnaire asked parents to report their child's age at diagnosis of hearing loss and hearing aid fitting, if applicable.

Table 1. Participant characteristics

	CHH (n = 59)
Age (years)	M = 12.1 (SD = 1.2)
Sex	Female = 29 Male = 30
Better-ear PTA (dB HL)	M = 46.5 (SD = 14.6)
Age at confirmation of hearing loss (months)	M = 21.6 (SD = 25.7)
Age at hearing aid fitting (months)	M = 23.8 (SD = 28.9)
CHH = Children who are hard of hearing; PTA = Pure-tone average; HL = hearing level	

2.3.1. Audiometric assessment

Pure-tone audiometric testing was completed via air conduction and bone conduction. Thresholds were measured at octave frequencies from 250 Hz – 8000 Hz in each ear using ER-3A insert earphones with foam tips.

2.3.2. *Dual-task experiment*

The speech stimuli were delivered via custom programming on the experimenter's computer. The auditory output was routed from an audiometer to loudspeakers.

The *primary task* involved repeating back sentences, using sentence stimuli from the Hearing in Noise Test (HINT; Soli & Wong, 2008). The *secondary task* was a simple visual reaction time task [16], presented and measured through E-Prime. Participants pushed the space bar in response to seeing a word (red, blue, yellow, green, randomly presented) appear on a computer screen. The participants did not need to perform any action other than pushing the space bar when the word appears. One visual stimulus item is presented with one HINT sentence per trial (visual stimuli are presented randomly during the second half of each HINT sentence, to maximize processing load). Conditions varied in difficulty based on the signal-to-noise ratio (SNR; +6, +2, -2 SNR dB). For each condition, two HINT lists were presented. Participants responded to 20 sentences and 20 visual stimuli per trial. Reaction time was the time between stimulus word onset and the space bar being pushed. For each participant we calculated the median of the 20 reaction times in a condition. This median score served as the reaction time for each SNR condition. Medians instead of means were used to control for outliers. Outliers were also dealt with by removing reaction time values that were below or above boundaries set by 1.5 times the inter-quartile range from the analysis [6]. False alarms and misses were recorded and removed from the dataset.

2.3.3. Subjective ratings

Participants rated their perceived effort on a 10-point scale. Participants rated the primary task ("How much effort did you put into repeating the sentences?") by responding verbally and marking it on visual analog scale. The experimenter asked the questions while the participants read the questions and looked at the scale. Pre-test training on the subjective ratings included three practice items that encouraged utilization of the entire scale.

2.3.4. Audibility calculations

The Speech Intelligibility Index (SII) was calculated for aided audibility by entering the audiometric thresholds for each ear of each participant for average (65 dB SPL) input levels. Better-ear aided SII values were estimated as the highest aided SII between ears for each child.

2.2.5 Language and cognitive assessments

A subtest of the Automated Working Memory Assessment (AWMA; [17]) related to working memory capacity (Odd One Out) was completed. Odd One Out will be used because of its minimal linguistic load. The Peabody Picture Vocabulary Test – 4th edition (PPVT-4; [18]) was used to assess receptive vocabulary.

2.2.6 Data Analysis and Statistical Approach

Primary task performance was measured as percent-correct (words correct/total words). Secondary task performance was measured as a difference score to control for variation in baseline reaction times: the median baseline reaction times (RT_B) were subtracted from the dual-task median reaction times (RT_{DT}) to calculate difference scores ($RT_{DT} – RT_B$). Linear regression models with 1) speech recognition percent-correct, 2) reaction time difference scores, and 3) subjective ratings at each of the noise level conditions as the outcome variables were used to determine the effect of aided audibility with working memory and vocabulary as potential mediators. Age at testing was controlled for in every model.

3. RESULTS

Preliminary analyses indicate that aided SII did not have a significant effect on primary task performance (i.e., percent-correct on the HINT) ($t[54] = 1.12$, $p = .2658$). There was a significant negative association between aided SII and subjective self-report ratings of listening effort ($t[54] = -2.60$, $p = .0119$) suggesting that as aided SII increased, perceived listening effort decreased. The effect of noise level was also significant, indicating that speech perception performance was higher and perceived listening effort was lower at more favorable SNRs.

4. DISCUSSION

Many children with mild to severe hearing loss are identified and receive early intervention at very young ages. Even with this early intervention, however, CHH experience challenges with communication due to reduced access to the auditory signal. These challenges are further compounded in school because CHH have increased difficulty perceiving speech in adverse acoustic conditions and most listening conditions are characterized by poor acoustics. When listening in adverse conditions, CHH must exert additional cognitive resources compared to children with normal hearing in order to perceive an incoming message. Consequently, they have fewer cognitive resources available to perform additional tasks and must expend increased listening effort. Listening effort requires the coordination of low-level, bottom-up processes, and higher-level, top-down processes. There is a lack of evidence regarding the interplay between auditory access and higher-level cognitive skills in influencing individual differences in listening effort for CHH. This knowledge gap hinders the understanding of the underlying mechanisms that drive listening effort in children with hearing loss, which in turn, limits the ability to develop evidence-based interventions for this population. The current study sought to determine the factors that underlie increased listening effort in school-age CHH. This study was based on a limited resources capacity theory, which posits that listeners require additional cognitive resources to maintain optimal listening performance during adverse acoustic conditions, and this demand on resources results in a decline in performance on secondary tasks.

The data generated from this study informs theoretical models regarding the integration of low-level, acoustic-phonetic input and higher-level, cognitive-linguistic processes involved in listening effort in school-age children. These findings have the potential to provide insight into the ways in which we can help CHH cope with classroom listening demands.

5. ACKNOWLEDGMENTS

This work was supported by research grants from the National Institutes of Health National Institute on Deafness and Other Communication Disorders under award number R21 DC015832.

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