Sentence processing speed of deaf and hard-of-hearing children in noise: Effects of normal vs. fast speaking rate

Rosanne Abrahamse[1,2], Rebecca Holt[1], Nan Xu Rattanasone[1], Titia Benders[1,3], Joerg M. Buchholz[1], & Katherine Demuth[1]
[1]Macquarie University, [2]Royal Dutch Auris Group, [3]University of Amsterdam

The Ease of Language Understanding (ELU) model [1] proposes that spoken language processing is slower under conditions of signal degradation as listeners must resolve perceptual mismatches between the incoming signal and existing lexical representations. Deaf and hard-of-hearing (DHH) children experience a chronically degraded input signal and, in line with the ELU model, process language more slowly than peers with normal hearing (NH) [2,3]. This may pose a major barrier to effective learning and socialising for these children, as they may struggle to 'keep up' in conversation. Furthermore, classrooms and playgrounds, where most learning and socialisation occur, are dynamic and noisy with speech occurring at varying rates, including fast speech with compressed acoustic cues. Little is known about how these environmental sources of signal degradation affect processing speed for spoken sentences among DHH children (though see [4,5] for single words). It is essential to better understand the factors driving slow language processing in this population to facilitate learning and communication. Therefore, this study aimed to determine whether DHH children process spoken sentences in noise slower than peers with NH, and whether this would be exacerbated by fast speech. We hypothesised DHH children would process sentences in noise slower than NH peers even at a normal rate, and that fast speech would cause further processing delays disproportionately affecting DHH children.

Thirty-one monolingual English-speaking 7-13-year-old DHH children (bilateral cochlear implants n=7, bilateral hearing aids n=10, bimodal fittings n=3, unilateral loss n=11) and 27 peers with NH completed an Auditory Word Detection Task to assess their language processing speed. Sentences were presented in 16-talker babble noise (+4dB signal-to-noise ratio) at a normal (4.5 syllables/second) or fast speaking rate (6.1 syllables/second). For each trial (n=24 per condition), a target word (e.g., *bus*) and corresponding image were presented in quiet, followed by a sentence in noise containing the target word (e.g., *Noah can travel on his own; he often takes the **bus** or the train to his aunt's house*; Fig.1). Participants made a keypress when they identified the target word in the sentence. Response times (from target word onset to keypress) were rank transformed and analysed using linear mixed-effects models. Significant main effects of Group (DHH vs. NH; $p<.001$) and Speaking rate (normal vs. fast; $p<.001$) were found: DHH children processed spoken sentences in noise slower than children with NH, and both groups processed speech slower in the fast compared to normal speaking rate (Fig. 2). The Group x Speaking rate interaction was not significant. Slower processing among DHH children was found for all hearing device configurations, including bilateral and unilateral losses.

Therefore, our hypothesis that DHH children would process sentences in noise slower than peers with NH was upheld. However, while fast speech was also found to slow processing, this effect was not modulated by group: there was no evidence for a *disproportionate* impact of fast speech on the processing speed of DHH children. These findings align with the predictions of the ELU model: with increasing signal degradation (i.e., the addition of fast speech on top of noise), processing was increasingly slow. Although DHH children were not disproportionately affected by the addition of fast speech to noise, even additive effects of noise and fast speech in the classroom may place DHH children at a significant disadvantage. Teachers may consider avoiding fast speaking rates to benefit their students, both with and without hearing difficulties.

References

[1] Rönnberg, J., Lunner, T., Zekveld, A., Sörqvist, P., Danielsson, H., Lyxell, B., Dahlström, Ö., et al. (2013). "The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances," Front. Syst. Neurosci., 7, 1–17.
[2] Holt, C. M., Demuth, K., and Yuen, I. (2016). "The use of prosodic cues in sentence processing by prelingually deaf users of cochlear implants," Ear Hear., 37, e256-e262.
[3] Holt, R., Bruggeman, L., and Demuth, K. (2023). "Effects of hearing loss and audio-visual cues on children's speech processing speed," Speech Commun., 146, 11–21.
[4] McGarrigle, R., Gustafson, S. J., Hornsby, B. W. Y., and Bess, F. H. (2019). "Behavioral measures of listening effort in school-age children: Examining the effects of signal-to-noise ratio, hearing loss, and amplification," Ear Hear., 40, 381–392.
[5] Oosthuizen, I., Picou, E. M., Pottas, L., Myburgh, H. C., and Swanepoel, D. W. (2021). "Listening effort in school-age children with normal hearing compared to children with limited useable hearing unilaterally," Am. J. Audiol., 30, 309–324.

Figure 1 – Visual representation of an example trial from the Auditory Word Detection Task, showing presentation of the target word in quiet followed by the sentence in 16-talker babble noise. Image corresponding to the target word (here *'bus'*) shown on-screen throughout.

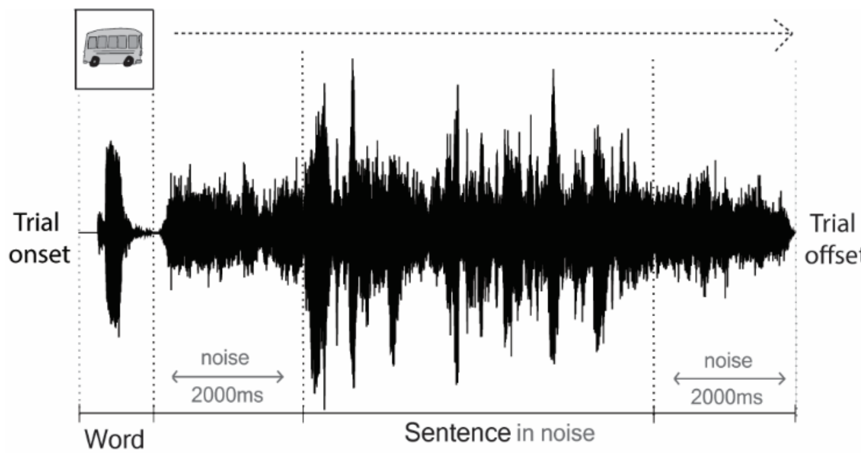

Figure 2 – Mean rank-transformed response times for normal hearing (left) and deaf and hard-of-hearing (right) groups. Normal speaking rate in dark grey, fast speaking rate in light grey. Higher percentile rank scores reflect slower responses. Error bars show 95% confidence intervals of the mean.