ADULTS WITH A SEVERE-TO-PROFOUND HEARING IMPAIRMENT. INVESTIGATING THE EFFECTS OF LINGUISTIC CONTEXT ON SPEECH PERCEPTION

Mark C. Flynn, Richard C. Dowell, & Graeme M. Clark

Department of Otolaryngology
The University of Melbourne
172 Victoria Parade
East Melbourne, 3002
Australia

ABSTRACT

Linguistic context is known to influence speech perception abilities in adults with normal hearing. Recent reports question the importance of context for adults with a severe-to-profound hearing impairment. The severe reduction and distortion in acoustic input may result in the listener perceiving insufficient acoustic-phonetic cues to allow access to higher level linguistic processing. To investigate this further, a detailed study of the speech recognition of adults with a severe-to-profound hearing impairment (N=34) was undertaken. A series of aided speech recognition tasks, sequentially examined the different levels of processing in the speech perception chain. The investigation concluded that the effects of severe-to-profound hearing impairment did not reduce the listener's ability to take advantage of contextual cues. There was, however, wide variability between participants in the utilisation of contextual processing. This indicates that to estimate "real-life" speech perception skills, an evaluation of contextual processing ability is required.

1. INTRODUCTION

Different tests of speech perception vary in the amount of contextual cues offered to listeners. As we proceed from tests of segmental perception, to tests of word recognition, and then to tests where those same words are inserted into sentences the amount of available contextual information increases. Closed-set vowel and consonant tests assess how well people perceive speech based primarily on acoustic features. Tests of open-set word perception examine how listeners use the available acoustic trace to withdraw word meanings from their semantic system (1,2). As conversational speech involves the perception of words embedded in sentences, open-set tests of sentence recognition examine the effects of syntactic context, co-articulation, and prosody. Additionally, investigation can take place into contextual factors beyond the stimulus sentence. These factors could include prior knowledge of the sentence topic and/or by making each sentence within the list related as in a narrative. A well-chosen test battery allows the investigation of each level of speech perception, and the relationship between them.

From these assumptions, it appears logical to assume that test materials, high in contextual information, should be easier to perceive. This assumption, however, is not universally accepted. Several authors (3, 4) suggest that if the incoming auditory signal becomes severely distorted, as is often the case for adults with a substantial sensorineural hearing impairment, then the listener may not receive the additional assistance of contextual cues. Similarly, while group performance may show an improvement for materials that are high in context, not all individuals may demonstrate this improvement. Investigation of the variability in contextual processing across participants may be useful in understanding this aspect of speech perception and perhaps, in showing how it could be improved. Possible reasons for poor use of contextual cues in adults with a severe-to-profound hearing impairment are the degree of distortion affecting the acoustic input and/or less efficient linguistic processing abilities.

Mean scores can be used to make comparisons between one type of test and another, but are limited in demonstrating the use of contextual information or in comparing across studies. Boothroyd (5) and Boothroyd and Nittrouer (1) proposed a solution through the use of predictions from probability theory. Two values (k and j) were used to describe the effects of context. The k factor relates to the proportional increase in channels of statistically important information available in the stimulus (1). For example, Boothroyd and Nittrouer (1) found a k value of 1.3 for recognition of known words compared with nonsense syllables, indicating that the influence of lexical context is equivalent to increasing by 1.3 the number of channels of statistically independent information in nonsense syllables. Similarly, the j factor is the effective number of statistically independent parts within a whole. For instance, Boothroyd and Nittrouer (1) found that CVC words of three different phonemes/parts were perceived as if they contained only 2.5 independent parts. Consequently, by using probability theory it is possible to obtain a quantitative estimate of the facilitative effects of context, which provides more information than reporting the mean difference between scores.

In summary, the aim of this investigation is to examine two questions. Firstly, does a severe-to-profound hearing impairment affect a person's ability to extract contextual information? Secondly, if contextual processing does occur, is it uniform across participants and therefore predictable?

2. METHOD

2.1. Participants

Thirty-four participants with a severe-to-profound sensorineural hearing loss (PTA = 61-98dBHL) participated in this investigation. All participants used oral language as their primary means of communication. All wore currently fitted hearing aids, which adhered to the NAL-R prescription (6) as verified by real-ear measurements and an SPL-o-gram.

2.2. Materials

The speech perception materials used in this investigation consisted of the following speech perception test lists;

- Closed-set test of the 12 vowels of Australian English.
- Closed-set test of the 24 consonants of Australian English.
- Open-set test of word recognition (CNC) (7, 8).
- Open-set test of sentence recognition (CUNY) (9).
- Connected Speech Test version 2 (CSTv2) (10).

Tests at the sentence level were also conducted in background noise (four-talkers superimposed) to replicate environments more typical of everyday listening conditions. An Australian male speaker pre-recorded all materials on CD.

2.3. Procedure

All test materials were presented via loudspeaker in the free field. The loudspeaker was located one metre away from the participant at 0^{o} azimuth. The materials were presented at 70dBSPL (peak level). Where appropriate, background noise (four talkers superimposed) was presented from the same loudspeaker. A period of practice was included within the design as well as a random order of presentation. This reduced the effects of practice and test order.

3. RESULTS AND DISCUSSION

A previous article (11) reported the mean scores and standard deviations of this group. The focus of the present discussion relates to the integration of these findings and an examination of contextual effects. The results indicated that at each level of acoustic processing there was a significant effect for context.

Closed-set tests of vowel and consonant recognition assessed the ability of the acoustic analysis system to perceive acoustic features. Performance on both of the segmental tests was primarily explained by factors relating to audibility. Error patterns were largely predictable from acoustic features and consistent with previous reports (12-16). For perception of vowels, the features of duration and locus of the first formant were well perceived with perception of the locus of the second formant being less well perceived. For consonant perception, voicing information was transmitted well with decreased transmission for manner and especially place.

It has previously been assumed that the perception of consonants and vowels was predominantly a non-linguistic task, which does not involve a significant amount of higher order processing. A significant effect ($p<.0001$) was found for the number of responses for a particular consonant and its frequency of occurrence in English. When in doubt, the participants were more likely to guess the more common consonant. For example, if the participant identified the consonant was a nasal, but could not identify place information, they were most likely to select the /n/ nasal, as it is the most common in English. Therefore, tests of acoustic feature perception should not be compared across languages or populations without taking into account the effects of phoneme frequency. Similarly, perception of the features of duration and formant locus in the case of vowels, and voicing, manner and place for consonants may interact to reduce the possible set. For example, the correct perception of one feature, such as nasality, reduces the potential set from 24 to 3 consonants. The potential set depends on what features were perceived and the language of testing. Consequently, these results suggest that acoustic perception has some previously unreported metalinguistic processing assisting correct identification. Additionally, care should be taken when comparing speech perception across languages because of differences in phoneme frequency.

From the scores for consonant and vowel perception a predicted CNC word score of 68.5% was obtained, compared with the participants' actual mean score of 75.2% (11). This improvement in score over the prediction was also noted in that 30/34 participants' actual CNC phoneme score was higher than their prediction. A Mann-Whitney signed rank test confirmed that there was a significant difference ($p<.05$) between the predicted and actual scores. This indicates the facilitative effect of using the lexical and phonotactic rules to assist phonemic perception. Additionally, it showed that monosyllabic word scores could be predicted from the segmental tests with an allowance for lexical effects.

Similarly, it was hypothesised that not all of the phonemic or acoustical information contained in a test word is required for correct identification. The results for phoneme and word scores were further analysed to determine j and k values (1, 5). Comparisons between the phoneme score and the word score indicating a k value of 1.3 indicating that the effect of embedding phonemes in known CNC words resulted in an increase in the number of statistically independent channels by 30%. Alternatively, although CNC words consist of three parts, the lexical effects reduce the effective independent parts to 2.49 (j value). Consequently, access to the lexical form of the word increases the possibility of the word being recognised. More importantly, this j value of 2.49 was consistent with the result of 2.46 for adults with normal hearing (1), 2.54 for adults with a mild-to-moderate hearing impairment (17) and 2.57 for cochlear implantees (18). Consequently, the type or degree of hearing impairment does not appear to effect the ability to process contextual information.

As discussed previously, testing of words in sentences aids the recognition of the individual word. This is facilitated by the increase in linguistic information now available to the person with a hearing impairment. This increase comes from the addition of syntactic, semantic and pragmatic information. It was hypothesised by some researchers that adults with a severe-

to-profound hearing impairment would be unable to access this information (3, 4). Fortunately, the results of the present study found that participants with a severe-to-profound hearing impairment were able to take advantage of linguistic cues and contextual processing across a varied range of speech perception measures. The presentation of words in sentences resulted in a 70% (k = 1.7) increase in the number of statistically independent channels available to the participant.

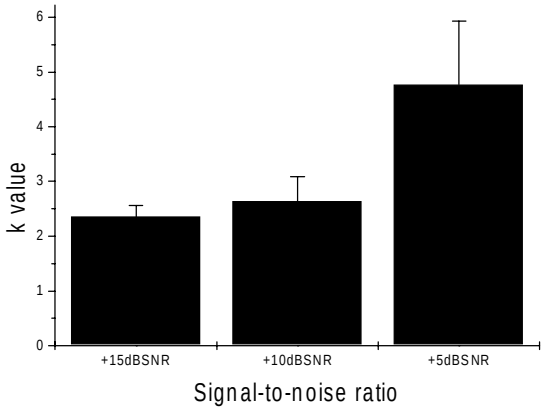

Figure 1: Comparison between the k values (CUNY compared with CSTv2) at each signal-to-noise level.

As expected, the increase in context available with the CSTv2 sentences, where the sentences are related not only to a central topic but also to each other, is considerable. Comparisons between the CUNY sentence lists and the CSTv2 paragraph pairs found that a decrease in signal-to-nose ratio from +15dBSNR to +5dBSNR resulted in an increase in the use of contextual information (Figure 1). Additionally, the k value showed a consistent increase from 1.3 for tests of word perception, to 1.7 for tests of sentence perception to over 2.4 for contextually related sentences. Consequently, contextual processing appears to increase, for this population, not only as the tests become increasingly linguistically based, but also as the acoustic conditions deteriorate with background noise. It is important, however, to note that this improvement with context was not uniform. Figure 2 shows clearly that some participants demonstrated large gains in information transmitted with the addition of contextual cues whereas other participants showed little or no improvement. Additionally, this variability was independent of pure-tone average and the other speech perception tests. Therefore, if we wish to estimate a person's "real-life" speech perception skills then we need to begin to evaluate the effects of contextual processing in quasi "real-life" communication situations.

This variability in performance may reflect differing metalinguistic skills between listeners, which are not assessed using conventional speech perception measures. The difference between traditional and context laden tests of speech perception may be predictive of this ability to adapt and/or cope with a substantial hearing loss. Additionally, this may assist the clinician in determining how well a person will adapt to an amplification device. Irrespective of whether the device is an externally worn hearing aid or an implantable prosthesis, both devices may require a period of acclimatization (19 – 22). Studies have found that people vary in the time it takes to acclimatise (22). It may be that people who show a larger no-context/context test difference may be quicker at acclimatising to a new device. Conversely, people who show little difference between conditions may need extra time allocated in the clinic for rehabilitation and acclimatization. These assertions, not assessed in this study, require further investigation. The more linguistic information made available to the participant the better the performance on each test of speech perception.

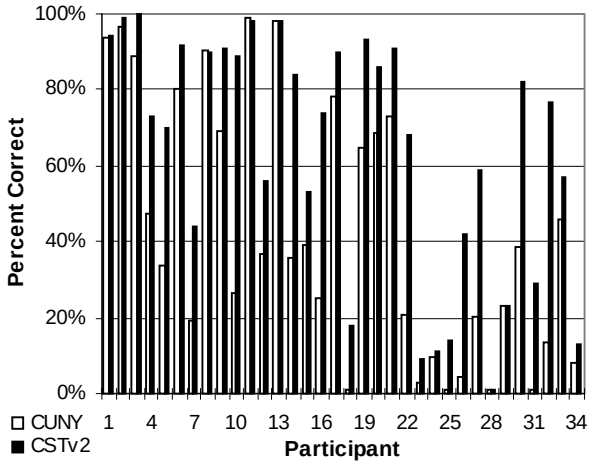

Figure 2: Comparison between CUNY sentences and CSTv2 sentences at +5dBSNR showing the wide degree of variability in performance between participants.

4. CONCLUSION

The results of the present study demonstrate that adults with a severe-to-profound hearing impairment continued to take advantage of contextual cues in a variety of speech perception assessments, across many levels of speech perception. Hence, poor residual hearing capacity does not diminish the potential for later lexical and/or contextual processing. As expected contextual and linguistic processing of the speech signal is greater in tests with a higher linguistic load. Additionally, the improved performance of individuals as the tests became more conversational indicates that traditional tests of speech perception may underestimate "real-life" speech perception abilities.

The variability observed between participants shows that people differ markedly in their ability to use contextual cues. This may help account for the clinical observation that some adults report very different abilities in understanding speech in their normal communication environment, despite identical audiometric configuration. Through the continued development of contextually based assessments researchers may learn more about factors, other than audiometric information, that help prediction of speech perception performance. Additionally, the ability to estimate the effect of contextual skills may assist in aural rehabilitation following the fitting of an amplification device or cochlear implant, in terms of predicting the amount of time required to acclimatise.

The present study shows that there exists the potential for linguistic or contextual processing within a variety of speech perception tests which assess performance from non-word segmental processing to open-set perception of context-laden sentences. It appears that no test of speech perception is completely isolated from the effects of linguistic skills and knowledge.

5. ACKNOWLEDGMENTS

The authors would like to particularly thank the efforts of Doris Kirn (Australian Hearing Services), the audiologists in the Department of Otolaryngology (The University of Melbourne), and the staff of the Cochlear Implant Clinic (RVEEH) for the time and energy they spent in locating potential participants for this study. This research was partially supported by an Australian Postgraduate Research Award and the Cooperative Research Centre for Cochlear Implant, Speech and Hearing Research.

6. REFRENCES

1. Boothroyd, A., and Nittrouer, S., "Mathematical treatment of context effects in phonemes and word recognition," *Journal of the Acoustical Society of America* 84(1): 101-114, 1988

2. Caplan, D., *Language: Structure, processing and disorders*, MIT, Cambridge, 1992.

3. Revoile, S., Kozma-Spytek, L., Holden-Pitt, L. D., Pickett J., and Dorge, J., "Acoustic-phonetic context considerations for speech recognition testing of hearing-impaired listeners," *Ear and Hearing* 16: 254-262, 1995.

4. Yacullo, W. S., and Hawkins, D. B., "Speech recognition in noise and reverberation by school age children," *Audiology* 26: 235-246, 1987.

5. Boothroyd, A, "Measurement of speech production in hearing-impaired children: Some benefits of forced choice testing." *Journal of Speech and Hearing Research* 28: 185-196, 1985.

6. Byrne, D., and Dillon, H., "The National Acoustic Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid," *Ear and Hearing* 7: 257-265, 1986.

7. Lehiste, I., and Peterson, G. E., "Linguistic considerations in the study of speech intelligibility," *Journal of the Acoustical Society of America* 31: 280-286, 1959.

8. Peterson, G. E., and Lehiste, L., "Revised CNC lists for auditory tests," *Journal of Speech and Hearing Disorders* 27: 62-70, 1962.

9. Boothroyd, A., Hanin, L., and Hnath, T., *A sentence test of speech perception: reliability, set equivalence, and short term learning. Internal report RCI 10.* City University of New York, New York, 1985.

10. Cox, R. M., Alexander, G. C., Gilmore, C., and Pusakulich, K.M., "Use of the connected speech test (CST) with hearing-impaired listeners," *Ear and Hearing* 9: 198-207, 1988.

11. Flynn, M. C., Dowell, R. C., & Clark, G. M., "Aided speech recognition abilities of adults with a severe or severe-to-profound hearing loss," *Journal of Speech, Language and Hearing Research* 41: 285-299, 1998.

12. Miller, G. A., "The perception of speech," in M. Halle (Ed.), *For Roman Jakobson*, Mouton & Co, The Hague, 1956.

13. Miller, G. A., and Nicely, P. E. "An analysis of perceptual confusions among some English consonants," *Journal of the Acoustical Society of America* 27: 338-352, 1955.

14. Moore, B, *Perceptual consequences of cochlear damage*, Oxford Medical Publications, Oxford, 1995.

15. Owens, E., Talbott, C. B., and Schubert, E. D., "Vowel discrimination of hearing-impaired listeners," *Journal of Speech and Hearing Research* 11: 648-655, 1968.

16. Wang, M. D., and Bilger, R. C., "Consonant confusion in noise: a study of perceptual features," *Journal of the Acoustical Society of America* 54, 1248-1266, 1973.

17. Olsen, W. O., Van Tassell, D. J., and Speaks, C. E., "Phoneme and word recognition for words in isolation and in sentences," *Ear and Hearing* 18: 175-188, 1997.

18. Rabinowitz, W. M., Eddington, D. K., Delhorne, L. A., and Cuneo, P. A., "Relations among different measures of speech reception in subjects using a cochlear implant," *Journal of the Acoustical Society of America* 92: 1869-1881, 1992.

19. Gatehouse, S., "The time course and magnitude of perceptual acclimatization to frequency responses: Evidence from monaural fitting of hearing aids," *Journal of the Acoustical Society of America* 92: 1258-1268, 1992.

20. Gatehouse, S., "Role of perceptual acclimatization in the selection of frequency responses for hearing aids," *Journal of the American Academy of Audiology* 4: 296-306, 1993.

21. Turner, C. W., Humes, L. E., Bentler, R. A., and Cox, R. M., "A review of past research on changes in hearing aid benefit over time," *Ear and Hearing*, 17 (Supplement): 14s-28s, 1996.

22. Tyler, R. S., and Summerfield, A. Q., "Cochlear Implantation: Relationships with research on auditory deprivation and acclimatisation," *Ear and Hearing* 17 (Supplement): 38s-50s, 1996.