PREDICTING LANGUAGE SCORES FROM THE SPEECH PERCEPTION SCORES OF HEARING-IMPAIRED CHILDREN

Lois Martin and John Bench

School of Human Communication Sciences
La Trobe University, Victoria, Australia

ABSTRACT

The ability to understand speech in 27 hearing impaired children was assessed using the BKB/A Picture Related Sentence test for children. The mean sentence score for the group was 72% (range 100-18%). Language scores (CELF-R) and Verbal Scale IQ (WISC-R) scores were significantly below the norm (72.8 and 89.2 respectively). Performance Scale IQ scores were slightly above the norm (106.3). Sentences scores were correlated significantly with language score (r = 0.49). Further investigation showed that the predicability of language scores could be improved when sensation level was taken into account. Sensation level was negatively correlated with language scores (r = - 0.51), demonstrating that children with better language abilities perceived speech at relatively lower intensity levels. The observed sensation levels from the group were compared with the expected levels for normally hearing children. This difference measure yielded a correlation coefficient of - 0.73 with language scores.

1. INTRODUCTION

Speech tests are used in audiology to assess the receptive capabilities of the patient's auditory channel. Such tests are designed according to various linguistic dimensions such that stimulus items are typically nonsense syllables, words, or sentences. A percentage correct score is obtained under controlled acoustic conditions. Commonly used acoustic conditions include varying the presentation level of the stimulus items or the signal to noise ratio, but sometimes other dimensions are also manipulated such as the amount of frequency filtering. It is possible to derive from such tests a psychometric function where the subject's performance (percentage correct) can be plotted against the stimulus magnitude to produce a sigmoid shaped performance-intensity curve.

Psychometric functions vary according to the type of linguistic materials used in the test, the acoustic conditions of the test and the type of people being tested (specifically their linguistic background and hearing status). Thus the speech reception threshold (SRT: the level for the 50% score) of a closed set of words will be at a lower intensity level than open-set words. Filtering the frequencies of the acoustic signal will also adversely affect the presentation level needed to achieve a 50% score [1]. For the same listener, it can be said that stimuli are processed more efficiently according to their linguistic content and their acoustic composition. However, speech tests are clinically most useful when comparing one population with another. Thus the psychometric function of a particular test for a group of normally hearing subjects can be used to assess the detrimental effects of hearing loss on word recognition. For individuals with an acquired hearing loss (after the acquisition of speech and language) increasing the presentation level contributes significantly to restoration of approximately normal function, although the frequency configuration and degree of hearing loss also play an important part. The peripheral hearing loss disrupts the amount of sensory information available to the speech processing system for the word recognition task. These individuals have an impaired sensory channel but otherwise have normal speech and language processing capacity.

By contrast, individuals with a pre-lingual hearing loss develop their speech and language processing abilities via an impaired sensory channel. They typically do less well on speech perception tests than individuals with equivalent but post-lingual hearing loss. This difference between the two groups probably occurs because the lexical representations of the speech processing system are of an inferior quality for the pre-lingually hearing-impaired compared with the post-lingually impaired. Relatively poorer scores on a speech perception test could result from failure to utilise all the speech information represented in the auditory signal, with the consequence that it takes more context or stimulus magnitude to activate a lexical representation. Therefore the efficiency with which speech is processed on a speech perception test may reveal something about the status of lexical representations and the speech processing system in general. In this case we would expect to find a correlation between these measures of perceptual efficiency and linguistic abilities.

Two previous studies concerning this hypothesis have produced equivocal results. Bench and Cotter [2] found significant correlations between the gradients of speech curves for Fry Sentences [3], and the auditory and verbal subtests of the Illinios Test of Psycholinguistic Abilities: ITPA [4]. However, Bench, Kowal and Bamford [5] using a different set of subjects, did not find significant correlations between the gradients of curves for the BKB sentences and the same ITPA subtests. The authors suggested that these differences may have arisen because the Fry sentences were linguistically more demanding than the BKB sentences. This issue is reconsidered here in a study that took into account the sensation level at which sentence material was presented to a group of hearing-impaired children. While presentation level needs to be adjusted according to the overall degree of hearing loss, individuals who need less sensation level to achieve a perceptual outcome can be considered to be behaving more efficiently than those who need more sensation level.

2. METHOD

2.1. Subjects

Twenty-seven hearing-impaired children took part in the study. Their average age was 9 years 7 months (SD: 3;4) and their average hearing loss across five frequencies (250, 500, 1k, 2k and 4k Hz) was 66.5 dB HTL (SD: 16.5 dB).

2.1. Test Materials

Speech perception skills were assessed using the BKB/Australian Picture Related sentence test developed by Martin [6]. The new test has the same structure as the standard form of the BKB (Bamford-Kowal-Bench) sentence lists originally developed for hearing-impaired children [7, 8], but the sentences are cued by four pictures of everyday scenes that would be familiar to most Australian children. Each sentence list contains 16 sentences, with four sentences referring to something about the corresponding picture. The rationale for this format is the observation that speech perception in context is usually easier than without context, especially under adverse hearing conditions. Therefore, this test can be considered to assess assisted open-set word recognition.

The Clinical Evaluation of Language Fundamentals-Revised: CELF-R [9] was used to assess language abilities. A total language score is derived from six subtests assessing semantic, syntactic and memory skills using both expressive and receptive tasks.

Since intelligence may have a considerable influence over a child's ability to learn language, especially under adverse circumstances as with hearing loss, children were also assessed using the Wechsler Intelligence Scale for Children - Revised: WISC-R [10]. This test has the advantage of testing both verbal and performance intelligence. The performance scale can be considered as measuring intelligence where hearing loss has had minimal if any impact. Verbal scale scores have a greater potential to be influenced by hearing loss. A difference of approximately 12 points between the two scales is considered significant at the 5% level.

2.3. Procedure

Testing took place at the child’s school over three or more one hour sessions spread over several weeks. During the first session the child’s hearing was re-assessed if a recent audiogram was not available and the BKB/A PR sentence test was administered. Subjects were familiarised with each picture by means of an orientation procedure that described the action of the picture and required the child to answer some simple questions. A recorded list was then presented via an audiometer and headphones at appropriate levels for their degree of hearing loss. The child was required to repeat the words they had heard. More lists were administered at different intensity levels (to a maximum level of 120 dB SPL) in order to estimate the performance-intensity function. At the second session the CELF-R was administered and at the third session the WISC-R.

3. RESULTS

The maximum score obtained with the BKB/A PR sentence test was used for statistical comparisons. A mean score of 72.1% was obtained for the group overall (SD: 26.0%). The mean language score was 72.8 (SD: 16.0), based on a normalised measure with a mean of 100 and standard deviation of 15. The group’s overall performance on the language test was therefore nearly two standard deviations below that of their normally hearing peers. The WISC-R scales also have normalised scores (mean: 100, SD: 15). Group performance for the Verbal Scale was depressed relative to normal but to a lesser extent than the language measures (mean: 89.2, SD: 18.1). By contrast, the Performance Scale was slightly above the normal mean (mean: 106.3, SD: 18.2).

The degree of hearing loss was not significantly correlated with language scores from the CELF-R ($r = -0.14$), but the BKB/A PR sentence score was ($r = 0.49$).

3.1 Estimating sensation level

Sensation level for the maximum sentence score was estimated by subtracting the hearing thresholds from the presentation level of speech, to yield a suprathreshold value expressed in decibels. The presentation level of the speech materials was recorded as the output of the audiometer relative to the calibration tone of the sentence recording in dB SPL (set at 3 dB above the speech peaks). Hearing threshold levels (HTL) were converted to dB SPL, by adding the reference pressure for the minimal audible pressure (MAP) for a TDH 49 headphone with a MX41/AR cushion. The values designated by the Australian Standard [11] are 26.5 dB at 250 Hz, 13.5 dB at 500 Hz, 7.5 dB at 1000 Hz, 11.0 dB at 2000 Hz and 10.5 dB at 4000 Hz. The sensation level (SL) at a particular frequency was calculated by subtracting the hearing threshold in dB SPL from the presentation level (PL):

$$SL = PL - (HTL + MAP)$$

A five frequency average was then calculated to give an overall mean sensation level. Where the threshold level in SPL exceeded the presentation level a zero value for the sensation level was assigned to that frequency. This situation occurred with six subjects, who had deteriorating hearing levels in the high frequencies. In five cases a zero value for sensation level was assigned at 4000 Hz and in four cases at 2000 Hz.

The maximum sentence score for 11 subjects in the group was measured at the maximum output of the audiometer (Table 1). For 7 subjects this measure was taken 10 dB below this output level at 110 dB SPL, and 9 subjects achieved their maximum scores at intensities ranging from 70 to 100 dB SPL. The subjects in this latter category produced the highest sentence scores, while those in the first category produced the lowest scores on average.

The correlation between hearing loss and sensation level was not significant ($r = -0.325$, $p = 0.098$), indicating that the level of presentation was not chosen simply on the basis of degree of hearing loss. The correlation between sensation level and sentence score was not significant ($r = -0.017$, $p = 0.932$). Table 1 shows that when subjects were classified according to presentation level, the mean sensation level for each group was approximately 26 dB. Only two subjects had mean sensation levels of less than 20 dB when the presentation level for speech was 120 dB SPL. These two subjects had hearing losses of 94 and 93 dB HTL and scored 18% and 48% respectively. Possibly these subjects would have obtained higher scores if more amplification had been available to them. For other subjects in that group, it is possible to infer that adequate sensation level (relative to a normally hearing person) was provided but without the expected improvement in their sentence scores.

Level	Hearing loss 5FA[1]	Presentation Level dB SPL	Sensation Level dB	Sentence Score BKB/A PR
120 dB, n = 11				
Mean	79.36	120	27.15	54.73
SD	8.27	0	8.19	26.25
max	94	120	37.2	96
min	69	120	13.3	18
110 dB, n = 7				
Mean	70.29	110	26.53	72.86
SD	9.69	0	8.69	23.49
max	85	110	44.2	98
min	52	110	15.5	42
< 110 dB, n = 9				
Mean	48.22	87.78	26.16	92.56
SD	11.02	11.76	6.94	5.76
max	62	100	34.4	99.5
min	32	70	13.5	82

1. 5FA five frequency average hearing loss dB HTL

Table 1: Presentation level and sensation level for maximum sentence scores.

3.2 Selecting variables for the multiple regression equation

Having obtained an estimate of sensation level for the maximum speech score, it was possible to derive measures of speech processing efficiency. For consideration as a predictor variable, two criteria were adopted. Firstly, the measure should incorporate sentence score and sensation level parameters and, secondly, it should correlate significantly with the language scores. Table 2 lists the variables considered. Sentence scores (PR) and sensation level for that score (DBSL) correlate significantly with language scores (CELF-R), and individually would account for approximately 23-26% of the variance recorded in the scores. These two measures were then combined by dividing the sentence score by the sensation level to yield a measure of percent correct per dB of sensation level (RATESL). The result was an increase in the correlation coefficient and a consequent improvement in the explained variance (38.5%).

The RATESL variable treats an increase in sentence score as if it were improving linearly with increasing sensation level, but performance-intensity functions can be considered to be sigmoid in shape. The next variable to be considered (DIFF) related the sensation level of the observed scores from the hearing impaired subjects to the expected sensation level of normally hearing children as represented by the subjective calibration curve. Probit analysis was used to derive a common psychometric function from the scores of 10 normally hearing children.

	CELF-R		WISC-R Performance scale	
	R	*p*	R	*p*
PR	0.486	S	0.122	NS
DBSL	- 0.511	S	- 0.277	NS
RATESL	0.620	S	0.144	NS
DIFF	- 0.738	S	- 0.352	NS
PERF	0.518	S		

PR	BKB/A PR % correct score
DBSL	Sensation level in decibels
RATESL	PR divided by DBSL
DIFF	Difference between observed and expected sensation level for normal BKB/A PR speech curve

Table 2: Variables considered for inclusion in the linear regression analysis.

The DIFF variable was derived by taking the observed sentence score expressed as a proportion less than one, and obtaining the expected sensation level for that score from the reference curve. These calculations were obtained using the NORMINV function in Microsoft Excel version 5, which returns a value that is the inverse of the normal cumulative density function for a specified probability, mean and standard deviation. The expected sensation level was then subtracted from the actual sensation level to yield a difference in decibels. Two subjects scored 100% for the sentence test. These values were considered to be equivalent to a probability of 0.995, since a value of 1.0 cannot be computed. The mean DIFF measure was - 0.6 dB (SD: 10.9 dB, range: -16.9 to 24.8 dB). Positive DIFF values indicated that the subject's performance was achieved at a greater sensation level than would be expected from a normally hearing child. Negative values indicated that performance was achieved at less than normal sensation levels. Hence positive values indicate that efficiency of processing speech is less than normal and negative values are indicative of greater efficiency.

It is important to note that the relationship to the normal speech perception curve is relative rather than absolute. An arbitrary constant could be added to the sensation level of the hearing impaired subjects, giving the appearance that all subjects processed speech with less efficiency than a normally hearing child. However the correlation between the DIFF parameter and the language score would be unchanged. What has been achieved in deriving a DIFF measure is to anchor the speech processing scores of the hearing impaired subjects relative to one another. All subjects were equated with the same baseline (dB sensation level) and the scores of the hearing impaired subjects were compared to those of normally hearing children relative to that baseline.

3.3 Language scores as a function of the difference in expected and observed sensation level and WISC-R Performance Scale scores

A linear regression equation was calculated for CELF-R language scores as a function of DIFF variable and the WISC-R Performance Scale score, yielding a multiple R of 0.788, with 62.1 % (58.9% adjusted) of the variance accounted for. The regression (F (1, 25) = 19.6, $p < 0.001$) was statistically significant and both independent variables were also significant (DIFF: t = 4.7, $p < 0.001$; PERF: t = 2.2, $p < 0.05$). The regression equation associated with this analysis was:

$$\text{CELF-R} = -0.93\text{DIFF} + 0.26\ \text{PERF} + 44.8$$

A hierarchical regression analysis was carried out, controlling the entry of the variables into the regression equation. When DIFF was entered first, a significant regression was obtained (F (1,25) = 29.9, $p < 0.001$, $R^2 = 0.545$). Then, when PERF was added to the regression, the result was significant but its contribution much smaller, (F (1, 24) = 4.81, $p < 0.05$, $R^2 = 0.076$). Reversal of the procedure yielded a larger contribution from PERF, (F (1,25) = 9.168, $p < 0.001$, $R^2 = 0.268$), and a smaller but still significant contribution from DIFF, (F (1,24) = 22.29, $p < 0.001$, $R^2 = 0.352$). Thus when both variables are entered together or the largest contributing variable is followed by the remaining variable, speech processing efficiency has the largest effect accounting for 54.5% of the variance, with non-verbal intelligence contributing only 7.6%. Non-verbal intelligence improves its relative weighting to 26.8%, if it is given priority over speech processing efficiency which then contributes 35.2%.

4. DISCUSSION

This study demonstrated that the ability to recognise simple everyday sentences is correlated with more complex linguistic tasks for children with a pre-lingual hearing loss. A pre-requisite for any linguistic ability is the degree of lexical knowledge, for example the number of lexical items (vocabulary size), and their associated semantic and syntactic functions. A hitherto somewhat neglected area concerning the lexicon is the quality of the representations it contains, that is, how easily these representations are elicited by incoming auditory sensations or accessed for expressive purposes. Lexical representations can be activated through auditory speech tests and it was hypothesised that children who achieve not only higher scores but at lower sensation levels would have better quality representations and hence better linguistic abilities. This relationship between percentage correct and sensation level was characterised as efficiency of speech processing. When sensation level was related to performance as a predictor of language abilities, a higher correlation coefficient was obtained. An even higher correlation was obtained when these measures were related to the normal performance-intensity function. These results demonstrate the feasibility of the approach adopted in the present study. Further studies may not only replicate the results reported here but improve estimates of processing efficiency by using other acoustic conditions and speech tests more sensitive to the differences between population groups.

5. REFERENCES

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