The relationship between frequency discrimination skills and language development in 5-7 year olds

Kate Noonan[1], Edith L. Bavin[1], Ben Ong[1] and David Grayden[2,3]

[1] **School of Psychological Science, La Trobe University; [2] NICTA, Dept of Electrical & Electronic Engineering, University of Melbourne, [3] The Bionic Ear Institute, Melbourne**

Abstract

Research with infants has shown their auditory processing abilities predict subsequent language development. However, there are few studies that have investigated auditory processing skills of primary school-age children. This paper reports on a study that focused on a child-friendly method for testing auditory processing skills of children aged from 5-7 years. 36 children (M = 71.9 months) were tested on their discrimination of tone pairs that varied in frequency. Two pairs of tones were presented; one pair contained two 'same' tones (400 Hz) and the other pair contained two 'different' tones, one tone at 400 Hz and the other with a different frequency, ranging from 448 to 402 Hz. The tones were attributed to two animated frogs that appeared on a touch screen. The child was asked to identify which frog made the 'different' sound. Forward and backward masking conditions were included. The results showed variation in auditory processing skills, but differences between forward and backward masking were not significant. Significant correlations were found between auditory processing thresholds and expressive and receptive language. The findings suggest that children with poor frequency discrimination skills in the 5-7 year age range may be at risk for poor language outcomes.

1 Introduction

1.1 Language and auditory processing

Speech perception requires phoneme identification and involves rapid discrimination of formant frequencies in accordance with the rapidly changing articulations that occur in ongoing speech (Bailey & Snowling, 2002). A link between auditory processing and language proficiency has been established by a number of researchers (e.g., Benasich & Tallal, 2002; Saunders, Protopapas, Cangiano, Salz & Cerles 1998; Tallal, 2003; Tallal & Piercy, 1973). Some of this research has focussed on the auditory processing skills of individuals with specific language impairment (SLI). As argued by Benasich and Tallal (2002), crucial to language development is the ability to process and classify two or more rapidly changing auditory signals presented within a brief time frame. The temporal and spectral cues are important for discriminating the sounds of a language, and in order for language to develop, a child must be able to discriminate and categorize the sounds of their language (Kuhl, 2004).

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Benasich and Tallal (2002) conducted a longitudinal study to examine the performance of infants on brief, rapidly presented auditory stimuli; the infants either had no family history of language impairment or a positive family history. Infants were initially assessed at 6-9 months of age and followed up at 12, 16, 24 and 36 months of age. At time 1, auditory processing thresholds were measured using a forced-choice procedure: the infant was trained to associate an auditory tone sequence with a head-turn in one direction and another auditory tone sequence with a head-turn in the opposite direction. The results of the study showed that, regardless of family history, rapid auditory processing skills in infancy were the best predictor of language outcomes at age three. That is, the children who were better able to process brief, rapidly presented tones in infancy demonstrated better language development. In contrast, children who were poor at processing brief, rapidly presented tones, demonstrated poor language development at age three.

Auditory processing has also been investigated in children with SLI. SLI is identified if a child's language is below the normal range on a standardised language assessment but performance is in the normal range on tasks measuring nonverbal IQ in the absence of hearing deficits or known neurological or social developmental delay. Tallal and Piercy (1973) suggested that SLI stems from a deficit in perceiving the acoustic distinctions among successive brief sounds in speech, termed a rapid auditory processing deficit.

Tones are typically used as stimuli in auditory processing tasks as they convey the complex frequency and temporal characteristics of speech sounds, but have no semantic interpretation as in syllables - such as /ba/ and /pa/. Using tone stimuli, Tallal and Piercy (1973) compared the auditory processing abilities of children with and without SLI on a temporal order (auditory repetition) task and a discrimination task. In the auditory repetition task children were asked to repeat the sequence of tones, separated by interstimulus intervals (ISIs) of differing durations. In the discrimination task children indicated whether two tones presented were the same or different by pressing corresponding buttons on a box. When the ISIs exceeded 305ms, that is, when there was a long time gap between the tones, the children with SLI performed equivalent to the control children. However, when the interval between the tones was decreased, the performance of children with SLI was significantly impaired on both tasks. The children were asked to discriminate along one dimension (frequency) whilst the tones were presented rapidly (rapid auditory processing). That is, rapid auditory processing deficits, auditory discrimination deficits, or a combination of both, could explain the findings (McArthur & Bishop, 2004a; Wright et al, 1997).

Hill, Hogben and Bishop (2005) examined frequency discrimination thresholds in children with and without SLI and retested a subset of the children with SLI and of the age-matched controls 42 months later. At time 1 the children with SLI had poorer frequency discrimination thresholds than age-matched controls. Frequency discrimination abilities improved in both groups between the two testing sessions but, as at time 1, the children with SLI performed significantly worse on the frequency discrimination task than controls. Thompson, Cranford and Hoyer (1999) also examined developmental trends in frequency discrimination skills among 5 to 11-year-old children and in a group of adults. Most of the 5-year-olds were unable to learn the task. The 7-year-olds performed significantly worse than the 9 and 11-year-olds but the 9- and 11-year-olds performed equivalent to adults. The results could be interpreted in two ways: either the skills required to discriminate tones are not reached until the age of 7 years, or the demands of the task were not sensitive enough to detect discrimination abilities of children below the age of 7 years.

The study raises the issue of whether reliable results can be obtained from young children with such complex psychophysical tasks. In a previous study we tested 49 children aged 4 and 5-years (mean age 54 months) on tone discrimination and syllable discrimination tasks (Bavin, Grayden, Scott & Stefanakis, under review). We repeated the tasks and found significantly high correlations between the two sets of results, indicating reliability. However, children gave verbal responses ('same' or 'different') which has disadvantages for children with poor language skills.

There is other evidence that young children can be engaged in auditory processing tasks. A recent study by Boets, Wouters, van Wieringen and Ghesquiere (2006) examined the feasibility of administering complex psychophysical tasks to preschool children. Auditory processing skills were examined in two groups of 5-year-old children, one with a high familial risk and one with a low familial risk for dyslexia. Psychophysical thresholds were estimated using a forced-choice adaptive paradigm embedded within a computer game. The authors report reliable results, and that performance on tasks of frequency modulation and tone-in-noise detection were significantly related to phonological awareness skills.

A variation in assessing auditory perception skills is using forward and backward recognition masking. The tasks require participants to discriminate pitch differences when the target signal is preceded (forward mask) or followed (backward mask) by a comparison signal (the auditory mask; Massaro & Burke, 1991). Sutcliffe and Bishop (2005) found that adults and children had more difficulty with backward masking than forward masking. In one study, using touch screen responses, they examined frequency discrimination in children aged 6 and 8 years and a group of adults. Each tone pair contained either 2 comparison tones (400Hz) or 1 target tone of a higher frequency and 1 masking tone (400Hz). The task was to select the pair containing the target tone. Lower thresholds were found for forward than backward masking. The 6 year-olds performed significantly worse than the 8 year-olds and adults on the backward masking task, but no significant differences were found between the 8 year-olds and adults. That is, adult-level performance on backward masking tasks seems to develop later than adult-level performance on forward masking tasks (Buss et al., 1990).

1.2 The study

Auditory perception skills in infancy have been shown to be predictive of language outcome at 3 years of age (Benasich & Tallal, 2002). However, it is of value to investigate concurrent associations between auditory processing skills and language in the early school years. A study was designed to compare frequency discrimination abilities for forward and backward masking tasks in children aged 5-7 years and to investigate the relationship between auditory processing skills and language. Based on Sutcliffe and Bishop (2005), it was hypothesised that children's frequency discrimination thresholds would be lower for forward masking than for backward masking. It was also hypothesised that children with better (lower) frequency discrimination thresholds would score higher on a language assessment than those with poorer (higher) frequency discrimination thresholds.

The role of nonverbal ability in auditory processing has been investigated in only a few studies, with inconsistent findings. McArthur and Bishop (2004b), for example, found non-significant differences on nonverbal IQ between groups with poor and good frequency discrimination. In contrast, Deary (1994) found a small but significant relationship between frequency discrimination and both verbal and nonverbal performance scores. We included a matrix reasoning task to investigate this further.

2 Method

2.1 Participants

Data are reported for 36 children aged between 5 years, 2 months and 7 years, 3 months. There were 18 males (*M* age = 72.28 months, *SD* = 4.16) and 18 females (*M* age = 71.61 months, *SD* = 6.80). All children were recruited through primary schools in the regional towns of Maryborough and Ballarat, Australia. An additional four children participated in pilot testing of the stimuli and procedures. Data from six other children were excluded from analysis as their results on the auditory processing tasks indicated chance level performance: at several levels of tone difference these children discriminated between the tones sometimes but not consistently. None of the children had been identified as language impaired.

2.2 Measures

We included a hearing task on the day of testing to ensure all children could hear the stimuli and to familiarise them with listening to sounds through headphones. Tones of 500 Hz, 1000Hz, 2000Hz and 4000Hz were presented, first to the left ear and then the right ear, in 10dB steps from 60dB HL to 20db HL. Hearing within the normal range required a 20dB hearing level at all tested frequencies.

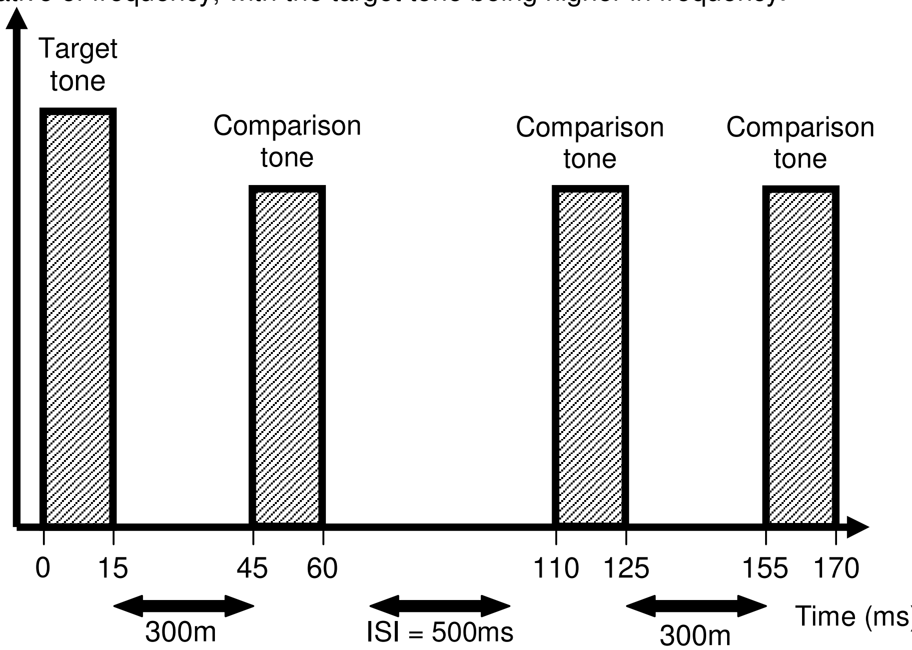
Two auditory processing tasks were used: a backward masking task and a forward masking task. In these two tasks four tones were presented (two pairs). The tasks were used to identify if children could detect a tone difference more easily if the high-pitched tone came before a low-pitched tone (backward masking) or if it came after the low-pitched tone (forward masking).

Backward masking task. In each trial, the target tone came before the comparative tone, in either the first tone pair or the second tone pair. The three comparison tones of each trial were 400Hz and the target tone was a higher frequency tone. The tones were synthesized electronically and involved a 400Hz – 400Hz tone pair and a higher frequency – 400HZ tone pair. Thus one tone pair contained two comparison tones of 400Hz, and the other contained one tone of a higher frequency and one comparison tone of 400Hz. In each pair, the duration of the tones was 150ms. Within each pair, the time between the two tones in a pair, the ISI, was 300ms. The two tone pairs were separated by 500ms (see Figure 1). The participant was required to select the tone pair that contained the higher frequency tone (the pair was referred to as 'beep-bow'). The higher frequency tone ranged from 448 to 402 Hz, beginning at 448Hz for easy discrimination and adaptively altered to become increasingly more difficult to discriminate.

Forward masking task. This task was identical to the backward masking task except the presentation order of the comparison and target tone was reversed so that the target tone came after the comparative tone in either the first or second tone pair. (The special pair to identify was referred to as 'bow-beep').

An adaptive transformed up-down procedure as described by Levitt (1971) was used. When an incorrect response was made the frequency of the different tone was increased; when a correct response was made the frequency of the different tone was decreased. The trials started with the different tone at 448 Hz. Changes were made in steps of 16Hz then 8 then 4, 2 and 1 Hz. The experiment was set up to present a fixed number of trials for each test in order to minimise differences in learning effects between children.

Figure 1. Timeline illustrating the onset and offset of stimuli in the backwards masking task with the target tone presented in the first tone pair. The height of the bars is indicative of frequency, with the target tone being higher in frequency.



For each trial, two cartoon frog images were presented on the computer screen (see appendix 2). They opened their mouths in turn, in synchrony with the tone pairs of each trial. This enabled a spatial and visual correlate of temporal order to assist the children in selecting the tone pair containing the target tone. The choice of which cartoon frog ‘uttered’ the tone pair with the target tone was chosen randomly by the computer for each presentation. Children were required to select which of the two animated images made the different tone (higher pitch sound) by touching it on the touch screen. Correct responses were visually and audibly reinforced with a change to the colour of the background for the frog (-> green), a friendly animated and audible croak and an advancement of a counter on the screen (See Figure 2). Incorrect responses were indicated with a red background and no advance of the counter.

Figure 2. Screen shot of the frequency threshold estimation task. With a correct response the counter advances. With an incorrect response the counter does not change.

All auditory tasks were administered through an external sound box for clear and consistent audio output. The sound box was a 24-bit Creative USB Sound Blaster (model SB0300) connected to a set of Digitor headphones (model C4116). The headphones were calibrated to 80 dB using a Bruel and Kjaer Type 2239 sound level meter for the forward and backward masking tasks and calibrated to 60 dB, 50 dB, 40 dB, 30 dB and 20 dB for the hearing task.

Language. The Clinical Evaluation of Language Fundamentals – Fourth Edition (CELF-4; Semel, Wiig & Secord, 2003) was used to measure the children's language. There are six core subtests; three provide a receptive language score and the other three provide an expressive language score

Non-verbal. The Matrix Reasoning subtest from the Wechsler Preschool and Primary Scale of Intelligence – Third Edition (WPPSI – III; Wechsler, 2002) was used to assess children's non-verbal skills.

2.3 Procedure

Testing was conducted in a quiet room in each primary school. Each child participated in two sessions of testing that lasted approximately one hour each. The expressive language subtests were audio-taped so that scoring could be completed later. In Session 1, the hearing task was administered and some of the subtests from the CELF-4 as well as an auditory processing task (forward or backward masking). In Session 2, approximately 1 week later, the other subtests from the CELF-4 were administered, the remaining frequency discrimination task (forward or backward masking task) and the matrix reasoning task. Half the children were given the forward masking task in the first session and the backward masking task in the second session; the other half were given the backward masking task in the first session and the forward masking task in the second.

For the frequency discrimination tasks the child sat in front of the touch screen wearing headphones, and was instructed to listen to the sounds. The test began when the child was attentive; the experimenter pressed a key on the key-board to start the trials. Familiarisation trials were used in each condition to ensure that the child understood the tasks. In the first set of familiarisation trials for each condition, 10 items were presented and the experimenter performed the trials alongside the child. In the second set, 20 trials were included and the experimenter provided verbal feedback and guidance to the child. Following familiarisation the 60 test trials began. The task took approximately 10 minutes. The task was repeated to determine test-retest reliability of the threshold results.

3 Results

Auditory frequency discrimination thresholds were measured in Hertz under forward and backward masking conditions. The program generated the average threshold since the 6^{th} change in frequency (reversal) as well as the average threshold since the 8^{th} reversal. Correlations between average threshold values since the 6^{th} and 8^{th} reversal data on both forward and backward masking tasks were extremely high, with Pearson's product-moment correlation coefficients of 1.0 for forward masking and 1.0 for backward masking. Because of the fixed number of trials in each condition, 15 participants did not reach the 8^{th} reversal on the forward masking task, and 3 participants did not reach the 8^{th} reversal on the backward masking task. Thus we used the average threshold since the 6^{th} reversal data in the analysis.

A Pearson product-moment correlation was conducted to determine reliability of the two testings for each condition. Auditory threshold estimates were found to be reliable under both forward (r = .83, p < .001) and backward (r = .82, p < .001) masking conditions. As the best level of performance for each participant was of interest, their lowest threshold was used for each condition. These are shown in Table 1, which also indicates whether forward or backward masking was tested in the first or second session.

Standardised indices of skewness and kurtosis of these threshold estimates fell within $z \pm 2.57$ ($\alpha = .01$) indicating that they were normally distributed. Preliminary analyses on the data revealed no gender or age effects and thus these variables were omitted from further analyses. An Analysis of Variance was conducted to compare frequency discrimination thresholds for the masking conditions, with test order as the between-subjects variable. While the means of the lowest frequency discrimination threshold values were higher on the backward masking than the forward masking task, the results of the analysis showed no significant effect of masking condition (F (1, 34) = 3.495, p = .07, η^2 = .09) and no significant interaction with test order (F (1, 34) = .833, p = .368, η^2 = .024).

Table 1. Descriptive Statistics of the Frequency Discrimination Thresholds for Forward and Backward Masking (lowest thresholds)

Auditory processing	*Order of testing*	*M*	*SD*	*Range*
Forward masking				
	1st	445.69	51.29	404.0-588.4
	2nd	447.30	42.49	402.5-527.7
Backward masking				
	1st	452.91	45.50	403.4-567.8
	2nd	468.30	50.19	405.3-559.9

The second set of analyses tested the hypothesis that language scores would be significantly associated with frequency discrimination thresholds. Table 2 presents the means and standard deviations of the standard scores for Receptive and Expressive language, as measured by the CELF-4, and non-verbal performance, as measured by the Matrix Reasoning task of the WPPSI-III. Correlations between auditory thresholds and language measures were computed to examine the association between auditory discrimination ability and language skills (CELF-4 Receptive and Expressive) and non-verbal skills (Matrix Reasoning).

Table 2. Standard Scores for Receptive Language and Expressive Language on the CELF-4 and the Matrix Subscale of the WPPSI-III

CELF-4	*M*	*SD*
Receptive language	100.61	14.33
Expressive language	103.42	10.40
WPPSI-III		
Matrix reasoning	10.90	2.77

In line with our predictions, there was a significant negative correlation between Receptive Language and the forward and backward masking threshold values, $r = -.35$, $p = .04$ and $r = -.41$, $p = .01$ respectively. There was also a significant negative correlation between Expressive Language and the forward masking threshold values, $r = -.38$, $p = .02$, and between Expressive Language and the backward masking threshold values, $r = -.41$, $p = .01$. That is, those children with lower frequency discrimination thresholds scored higher on receptive and expressive language.

There was also a significant correlation between Matrix Reasoning and forward masking, $r = -.37$, $p = .01$, backward masking, $r = -.61$ $p = .01$. Matrix Reasoning also correlated significantly with Expressive Language, $r = .41$, $p = .01$, but not Receptive Language, $p = .064$.

A multiple regression analysis was conducted to determine the contribution of forward masking, backward masking and Matrix Reasoning in predicting Expressive Language scores. The R^2 change was 24.6%, $p = .03$. That is, 24.6% of the variance for Expressive Language was contributed by children's auditory processing thresholds and their scores on Matrix Reasoning. However the squared semi partial correlations showed that most of the variance was shared; neither the .03 of variance contributed by forward masking or the .01 contributed by backward masking was statistically significant, and nor was the .04 for Matrix Reasoning. A second linear regression analysis was conducted to determine the contribution of forward and backward masking in predicting Receptive Language scores. The R^2 change was 19.4%, $p = .03$. That is, 19.4% of the variance for Receptive Language was contributed by the auditory processing thresholds. Again, most of the variance was shared. Neither of the squared semi partial correlations was statistically significant (.02 for forward masking and .07 for backward masking).

4 Discussion

The hypothesis that frequency discrimination thresholds would be significantly lower on a forward masking task than on a backward masking task was not supported, although lower mean thresholds scores were found for forward masking and there was a medium effect size. The significant correlation found between the thresholds for the two conditions indicates that they tap into similar skills.

Hartley, Wright, Hogan and Moore (2000) found that adult-level performance on backward masking tasks develops at approximately 12 years of age while adult-level performance on forward masking tasks develops at 7 to 9 years of age. Sutcliffe and Bishop (2005) found significant differences for 6 year olds on forward and backward masking tasks. Since there is a great deal of variation in performance on frequency discrimination tasks, different samples can lead to different findings. Different experimental demands may also affect performance. Buss, Hall, Grose and Dev (1999) suggest that attentional factors may be more pronounced for backward masking tasks than for forward masking tasks. Thus it would be useful to investigate attentional factors in future studies.

A difference between Sutcliffe and Bishop's study and the current study is the method used. Sutcliffe and Bishop used the parameter estimation by sequential testing (PEST) procedure, which estimated the 75% correct point on the psychometric function (Taylor & Creelman, 1967). The rationale for adopting the adaptive Levitt procedure in the current study was that in pilot testing using the PEST, the algorithm seemed to hunt unsuccessfully for the 75% point and thus was not providing a precise estimate of the children's thresholds. A quick estimate by sequential testing (QUEST) procedure, which optimally targets discriminatory abilities by focussing on the range in which thresholds lie for individuals, would have been an alternative since it requires a smaller number of trials, 20 or 30 trials as opposed to 60, to reach a sufficiently precise threshold result. However, this would have involved preliminary testing to set a target range for individuals.

We hypothesised that children who performed better on the language measures included would have significantly better frequency discrimination thresholds. This prediction was supported. Thresholds for forward and backward masking tasks were negatively correlated with receptive and expressive language scores. That is, children with higher (poorer) thresholds had lower language scores and children with better auditory processing scores had better language scores. Together, the forward and backward masking abilities contributed significant variance to receptive and expressive language scores.

We also investigated whether non verbal performance, as measured by a matrix reasoning task, were associated with expressive and receptive language scores. Children's scores on this task were correlated with expressive language but not receptive language but, as shown in regression analyses, they contributed no significant unique variance. That is, differences in expressive language scores are not dependent on children's cognitive ability independent of their auditory processing abilities.

5 Conclusion

As found in previous studies, we found variability in auditory processing abilities. While most reports have been for adults or older children, the current study shows variability is also found in children who are beginning their formal schooling. Some previous studies have reported learning effects; however, we repeated each task in the same session and found no such effects. The correlations were high between the two testings, indicating reliability for our measures. Nor did we find that for children of the age tested backward masking was significantly more difficult than forward masking.

The finding that frequency discrimination threshold values predict receptive and expressive language scores indicates that, even in the primary school years, auditory processing skills are related to language development. Auditory perceptual deficits might degrade the perception of the acoustic components of speech (Bishop, Carlyon, Deeks & Bishop, 1999). Given the importance of acoustic discriminations in conveying information in speech sounds, a reduced ability to discriminate frequency variations when forming phonological representations may continue to impede language development after infancy. The findings suggest that problems at the level of recognising and discriminating lower-level acoustic components may give rise to difficulties at higher level language processing. If children do not have the auditory processing skills to establish strong representations of language forms, it will affect their interpretation of the language they hear.

The procedure used in the current study was a significant improvement on much previous research. The use of visual material and touch screen responses kept the children attentive and focussed on the task. Sutcliffe and Bishop (2005) also used visual stimuli and a touch screen response. However, we believe the 'croaking' frogs in our study and the change in colours for a correct or incorrect response was an effective way of providing feedback, as was the counter showing the number of successful trials. These definitely helped maintain the children's interest and attention.

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