Development of a monosyllabic adaptive speech test for the identification of central auditory processing disorder

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INTRODUCTION

One category of tests that examine auditory processing disorders (APD) are the various versions of the "filtered words test" (FWT), whereby a monaural, low-redundancy speech sample is distorted by using filtering to modify its frequency content (Flowers et al., 1970; Willeford, 1977; Keith, 1986). Due to the richness of the neural pathways in the auditory system and the redundancy of acoustic information in spoken language, a normal listener is able to recognize speech even when parts of the signal are missing, whereas this ability is often impaired in listeners with APD (Bellis, 2003).

One limitation of the various versions of the FWT is that they are carried out using a constant level of low-pass filtering (e.g. a fixed 1 kHz corner frequency) which makes them prone to ceiling and floor effects (Farrer & Keith, 1981). In this study, we aimed to counter these effects by modifying the FWT to use a computer-based adaptive procedure, to improve the sensitivity of the test over its constant-level counterparts. Preliminary results from participants with normal auditory processing skills are presented.

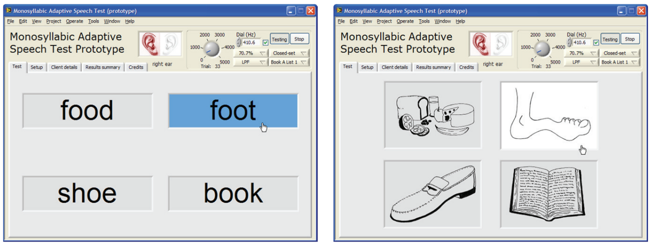

Figure 1: In this implementation of the four-alternative forced-choice (4AFC) test, participants used a touch-screen to select the word they thought they heard. The dial displaying the low-pass filter (LPF) corner frequency was usually hidden from view. This version of the test used written words (shown left), but subsequent versions incorporate pictures from the NU-CHIPS test book (shown right) to remove literacy as a confounding variable.

METHODS

Participants: 23 adult participants (mean age 29.8 ± 9.5 years) and 32 child participants (mean age 9.9 ± 1.3 years) participated in the study. Each participant was required to be free of known motor skill problems and had passed a pure-tone air-conduction screening test at 15 dB HL at octave intervals of 500 Hz through 4000 Hz. All child participants had passed either i) the SCAN-C screening test for APD or ii) a full APD test battery performed at the University of Canterbury Speech and Hearing Clinic. No attempt was made to control for gender throughout this study, as previous studies (Keith, 1986; Amos & Humes, 1998) suggested similar outcomes for males and females on tests of auditory processing. The male:female ratio was 1.4:1 and 1.8:1 for the child and adult participants, respectively. All protocols were approved by the University of Canterbury Human Ethics Committee (HEC Approval No. 2006/32).

Stimulus delivery: Recordings of the Northwestern University children's perception of speech (NU-CHIPS) test (Elliot & Katz, 1980) were taken from "Speech Recognition Materials" CD 1 (National Acoustic Laboratories, Chatswood, NSW, Australia). Stimulus delivery was controlled by UC MAST software developed by the authors using National Instruments LabVIEW 8.20. Presentation order of the 200 test items and screen location of the four alternatives were both randomised. Sound output from the PC was attenuated to 60 dB HL by an audiometer (either a GSI-61 audiometer, Grason-Stadler Corp., USA, or CE10 Clinical Hearing Evaluator, Interacoustics Corp, Denmark) and delivered by Telephonics TDH-39P supra-aural headphones in MX 41/AR cushions. Stimulus level was normalised with each presentation to compensate for the effect of the low-pass filtering. The average ambient sound level in the test environment was less than 40 dB A.

Test procedure: Using the Monosyllabic Adaptive Speech Test (MAST) of Mackie and Dermody (1986) as a starting point, we implemented a 4AFC procedure using NU-CHIPS test items. The first test item was low-pass filtered at 1 kHz using a "brick-wall" 32nd order Butterworth filter. Participants responded via an Elo ET1715L touch screen (Tyco Electronics Corp., USA). The LPF corner frequency for subsequent test items was determined by the adaptive algorithms. The 50% correct target was tracked using a simple 1-up-1-down method, while the 70.7% correct target was tracked using the 1-up-2-down transformed response method (Levitt, 1971). The initial step size of 12.5% of filter frequency reduced to 5% of filter frequency after the first 3 reversals. Threshold was calculated as the average of the mid-points of the last 13 reversals. An example adaptive track for an adult participant is shown in Figure 2.

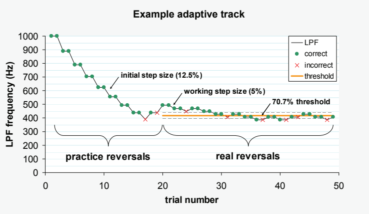

Figure 2: An example of an adaptive track for an adult participant. The measured 70.7% threshold of 417 Hz took 2 min 10 s (49 trials) to obtain.

RESULTS

As shown in Figure 3 below, there was a significant (p < 0.05) difference in the LPF corner frequencies at which children and adult participants scored either 50% or 70.7% correct, with adults achieving a score of 50% when stimuli were low-pass filtered at 419 ± 108 Hz (compared to 688 ± 193 Hz for children), and a score of 70.7% when stimuli were low-pass filtered at 662 ± 164 Hz (compared to 1009 ± 235 Hz for children).

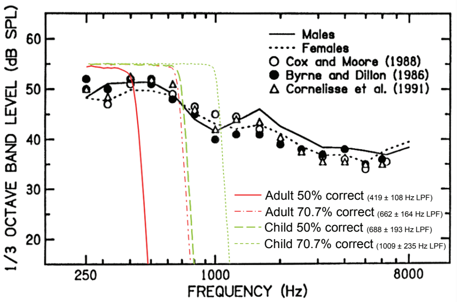

Figure 3: This figure shows the low-pass corner frequencies at which adult and child participants scored 50% and 70.7% correct. These low-pass filter functions are superimposed on a figure from Stelmachowicz et al. (1993) showing the long-term average speech spectrum for males (solid black line) and females (dashed black line). The area to the right of each filter function is removed from the speech stimuli in each condition. Adults performed better on both the 50% and 70.7% threshold tasks, as indicated by the larger amount of spectral information that needed to be removed from the stimuli for them to achieve those scores.

The test-retest reliability of the 70.7% task was also assessed for both adult and child participants. Because our pilot study indicated a significant learning effect (with scores improving as experience with processing low-pass filtered speech increased), we incorporated a binaural practise run to familiarise participants with the task, and increased the number of practise reversals. The adult participants showed no significant learning effect, but despite these protocol changes, the child participants still showed a significant improvement in performance between the first and second trials (paired t-test, p<0.001), as shown in Figure 4 below. This result is consistent with the findings of Amos and Humes (1998), who showed a significant improvement in the performance of children with a repeated administration of the Filtered Words subtest of the SCAN-C test. Once the learning effect had plateaued, the test-retest reliability for child participants was moderate.

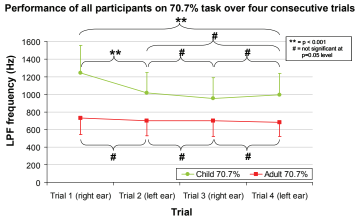

Figure 4: Means and standard deviations of 71% UC MAST threshold scores for the child (green circles) and adult (red squares) participants over four consecutive trials of the test. Testing was performed in two sessions, with Trials 1 & 2 followed by Trials 3 & 4 one week later. Adult participants showed no significant learning effect, but the child scores significantly improved between Trials 1 and 2 (paired t-test, p<0.001).

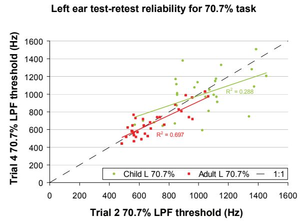

Figure 5: Scatter plot of 71% UC MAST left ear threshold scores for the child (green circles) and adult (red squares) participants on two trials separated by one week (Trials 2 and 4 from the previous figure). The Pearson correlation coefficients (r) of 0.835 for the adult data and 0.54 for the child data indicated strong and moderate reliability respectively.

The distribution of LPF corner frequencies as a function of age is shown in Figure 6. The performance of the child participants (aged 8.2 to 11.9 years) tended to improve with age, with the LPF corner frequencies at which they scored either 50% or 70.7% decreasing by around 5% per year. In contrast, the performance of the adult participants (aged 18 to 55 years) slowly deteriorated with age, with LPF corner frequencies increasing at about 0.9% per year.

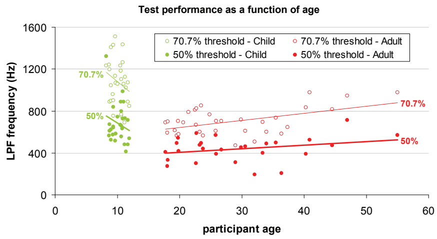

Figure 6: Test performance on the UC MAST plotted against the age of the participant. The ability of the child participants (green) to perform the computer-based filtered word test improved with increasing age, while the abilities of the adult participants (red) deteriorated slightly with increasing age. The 70.7% thresholds for 8 year old children were significantly higher (p = 0.019) than those for children aged 11. The 70.7% thresholds for adults under 35 years were significantly lower (p = 0.0014) than those for adults over 35 years of age.

DISCUSSION

The purpose of the present study was to improve the filtered word test, a form of monaural low-redundancy assessment for APD. Our computer-based implementation of an adaptive version of the test, called UC MAST, showed high test-retest reliability in adults, and moderate reliability in children once the initial learning effect had reached a plateau.

The improved performance of child participants with age is consistent with suggestions that neuromaturation of some portions of the auditory system may not be complete until age twelve or later (Ponton et al., 2000). To compare the performance of the UC MAST to standard APD test batteries, we have commenced trialing a modified version of this test on age-matched children with and without APD. The procedural modifications include using: i) a filter function that is less steep (to minimise phase distortion); ii) a weighted up/down staircase procedure (Kaernbach, 1991); and iii) pictures instead of words (as shown in Fig. 1). The reduced performance shown by the older adult participants, all of which had normal hearing below 4 kHz, indicates that the UC MAST filtered words test may actually show more promise as a test of auditory processing in older adult participants. While this test cannot by itself distinguish between age-related disorders of auditory processing and amodal cognitive function, the use of test items with spectral content almost entirely below 1 kHz does eliminate the well-documented influence of high-frequency audiometric threshold on test performance (see Humes, 2008).

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