Evaluation of (Central) Auditory Processing and Phonological/Phonemic Awareness in 6-Year-Old Children: A Pilot Study to Determine Test Efficiency and Inter-subject Reliability

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It is difficult to test auditory processing in children younger than 7 years of age due to poor inter-subject reliability and the limited attention spans of many younger children. These factors limit the ability of available tests to accurately identify (Central) Auditory Processing Disorder. The primary goal of the current study was to evaluate two tests of auditory processing and a test of phonological/phonemic awareness to determine if they could be administered efficiently to 6-year-olds with acceptable inter-subject reliability and an appropriate level of difficulty (in order for floor and ceiling effects to be avoided). The Pitch Pattern Sequence (PPS) test, a Compressed and Reverberated Speech Test (CRST), and subtests of the Queensland University Inventory of Literacy (QUIL) were given to 29 typically-developing New Zealand 6-year-olds. In general, the tests could be efficiently administered to children. Consistent with the literature, the participants demonstrated variable performance on all tests. Results indicate that it is probable to reliably assess auditory processing in younger children if adjustments are made to the tests to optimize error rates and reduce score variability across test items and lists.

Introduction

There is ongoing discussion and a lack of consensus regarding the exact nature and definition of a (central) auditory processing disorder ((C)APD) and, therefore, the best ways to assess, diagnose, and treat is not fully established (Bellis, 2007). Cacace and McFarland (2005) highlight the importance of evidence-based practice and the need for additional research in the area of (C)APD to ultimately come to a consensus. According to Friel-Patti (1999), disagreement concerning the definition of (C)APD may be due, in part, to the various disciplines attempting to understand it. It is likely that the heterogeneous nature of (C)APD accounts for at least some of the difficulty professionals have had establishing a standard definition. Despite the controversy, a (C)APD consensus group composed of scientists and clinicians concluded that "[C]APD may be broadly defined as a deficit in the processing of information that is specific to the auditory modality" (Jerger & Musiek, 2000, p. 468). More specifically, (C)APD has been described by the American Speech-Language-Hearing Association (ASHA) as "an observed deficiency in one or more" of the following behaviors: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition (e.g., temporal ordering), auditory performance with competing signals, and auditory performance with degraded signals" (ASHA, 1996, p. 41). A child with deficiencies of this nature typically exhibits difficulty maintaining auditory attention, following oral directions, retaining information presented orally, and understanding speech in noise or competing messages (Bamiou, Musiek, & Luxon, 2001; Chermak & Musiek, 1992). Teachers or parents who observe these difficulties may assume that the child has difficulty hearing and therefore refer the child for a hearing assessment. If peripheral hearing is found to be normal, (C)APD would be suspected and the evaluation process would begin.

Evaluation of Current Auditory Processing Measures

A multidisciplinary approach for the assessment and diagnosis of (C)APD is recommended (American Academy of Audiology [AAA], 2010; ASHA, 1996; Bamiou et al., 2001; Sharma, Purdy & Kelly, 2009; Witton, 2010). Multidisciplinary assessment enables the professionals involved to collectively determine the impact of the disorder on the person's ability to function in his/her everyday environments and, additionally, helps guide treatment and management decisions (ASHA, 2005). On the basis that (C) APD commonly coexists with speech and/or language disorders, such as specific language impairment (SLI; Bishop, Carlyon, Deeks, & Bishop, 1999) and dyslexia (Ramus, 2004), speech-language pathologists (SLPs) are frequently involved in the assessment of children with suspected (C)APD (ASHA, 2005). DeBonis and Donohue (2004) recommended that SLPs conduct informal assessments of the child's auditory perceptual skills, including auditory discrimination, auditory attention, and auditory memory abilities.

Behavioral measures of auditory processing have a central role in the audiological diagnosis of (C)APD. The following categories of auditory processing tests: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance with competing signals, dichotic listening and auditory performance with degraded signals can be assessed behaviorally (AAA, 2010; ASHA, 1996).

Two categories of these tests, specifically temporal processing and monaural low redundancy, are widely used in the assessment of children with suspected (C)APD (Bellis, 2003; Chermak et al., 2007; Emanuel, 2002; Emanuel, Ficca & Korczak, 2011; Krishnamurti, 2007). Because both temporal and monaural low redundancy tests are routinely used in clinical practice for the diagnostic assessment of children aged 7 years and older, these test categories were investigated here to determine their appropriateness for assessing auditory processing in younger children.

Temporal processing. Temporal tests assess the ability of a child to discriminate, sequence, and integrate auditory stimuli (Shinn, 2007). Generally, temporal tests utilize non-speech stimuli, such as tones and clicks (Bellis, 2003). For this reason, temporal tests are useful for the assessment of children for whom English is not their native language (Musiek & Chermak, 1994). Two of the most widely used temporal tests are the Frequency Pattern Test (FPT; Chermak, Silva, Nye, Hasbrouck, & Musiek, 2007; Musiek, 1994) and the Duration Pattern Test (DPT; Bellis, 2006; Chermak et al., 2007; Musiek, 1994). The FPT (Musiek, 1994) is one of several commercially available pitch pattern tests that all require the listener to report back the correct order of high and low pitched tones in a three-tone sequence. The FPT has high test efficiency and has been shown to identify auditory processing difficulties in children with learning difficulties and in persons with cochlear, brainstem, or cerebral lesions (Musiek, 1994). In a survey of 53 certified and/or licensed audiologists, Emanuel (2002) found that a pitch pattern sequence test was the most commonly used temporal test, with 76% of the 25 internet respondents and 61% of the 28 State of Maryland respondents reporting its use in the assessment of auditory processing. In a more recent survey of clinical practice, Emanuel, Ficca and Korczak (2011) reported that 79% of the respondents used a pitch pattern sequence test to assess temporal processing. According to Musiek and Chermak (1994), the FPT should be considered a first-order test for the assessment of auditory processing in children because of the good validity data and high sensitivity of this test. Friberg and McNamara (2010) questioned the validity of the FPT test, but noted its good sensitivity.

Monaural low redundancy. Monaural low-redundancy tests continue to be one of the most popular and widely used tests for evaluating central auditory function (Bellis, 2003; Krishnamurti, 2007). Typically, monaural low-redundancy tests involve the presentation of speech stimuli, which are either degraded by time compression and/or reverberation (Krishnamurti, 2007) or embedded in a competing signal to each ear individually (Bamiou et al., 2001). Tests of this nature reduce some of the extrinsic redundancy of the speech signal to assess a child's ability to fill in missing information and achieve auditory closure (Bellis, 2007). Many audiology clinics are now able to create monaural low-redundancy tests using computer software that can digitally compress, reverberate, or filter speech. Technology of this nature has enabled the removal of accent effects by permitting the recording of speech stimuli using a local native speaker of the language. Tests created using this computer software generate the need for a new set of normative data that is specific to each test.

Evaluation of Phonological/Phonemic Awareness

Phonological/phonemic awareness tests assess a child's awareness of the phonemes, onset and rhyme components, and syllables of spoken language (Larrivee & Catts, 1999; Rvachew, Ohberg, Grawburg & Heyding, 2003). Because (C)APD coexists with dyslexia in some children (ASHA 2005; Bamiou et al., 2001; Ramus, 2004) and phonological/phonemic awareness is a key skill underlying reading ability (Gillon, 2004), the assessment of phonological awareness may assist in the diagnosis and rehabilitation of children with (C)APD.

Phonological/phonemic awareness assessments, such as the Queensland University Inventory of Literacy (QUIL; Dodd, Holm, Orelemans, & McCormick, 1996) and the Test of Auditory Processing Skills (TAPS-3; Martin & Brownell, 2005*)*, may be administered when a child with suspected (C)APD is referred to a SLP. However, the link between performance on these tests and audiological assessments of (central) auditory processing is not known.

Young Children and (Central) Auditory Processing Assessment

The performance of young children on tests of (central) auditory processing is reportedly variable and, for this reason, children under the age of 7 years do not generally undergo full diagnostic evaluations for (C)APD (Bellis, 2003). High inter-subject variability among typically developing children has led to limited normative data for children under the age of 7 years (Musiek & Chermak, 1994). Variations in neuromaturation and attention may account for some of this variability. For some regions of the auditory system, neuromaturation may not be complete until the age of 12 years (Bellis, 2003, Tonnquist-Uhlen, Ponton, Eggermont, Kwong, & Don, 2003). Performance on the FPT is adult-like at age 12 years, but dichotic listening is significantly poorer in 12-year-olds than in adults (Bellis & Ross, 2011). This is not surprising as myelination of corpus callosum axons, important for interhemispheric transfer in dichotic listening tasks, may not be complete until late adolescence (Whitelaw & Yuskow, 2006). This is important given that the axons of the corpus callosum play a significant role in inter-hemispheric integration of auditory information (Whitelaw & Yuskow, 2006).

Despite the variability demonstrated by young school-aged children on (C)APD assessments, delaying auditory processing assessment (and a possible diagnosis) is undesirable. This is especially true since young children are believed to have greater neural plasticity and consequently more potential for functional change (Chermak & Musiek, 1992). Thus, a number of researchers have attempted to identify auditory processing assessments that are appropriate for younger children. Stollman and colleagues (2004b) examined the performance of 4-, 5-, and 6-year-olds on a (central) auditory processing test battery that included a sustained auditory attention test, a dichotic words test, a binaural masking-level difference test, an auditory word discrimination test, and a gap detection test. Additionally, phonemic awareness was assessed using the Lindamood Auditory Conceptualization (LAC) test. They found that, as expected, the performance of 6-year-olds was less variable than the performance of the 4-year-olds on five out of the six tests in the test battery, including tests of phonemic awareness and auditory discrimination (Stollman et al., 2004b).

Keith (2002) tested 6-year-olds on the Time Compressed Sentences Test (TCST) and found that, on average, 6-year-olds were able to repeat speech stimuli at 40% time compression with 93.4% accuracy (SD 8.9%), compared to 7-year-olds who were able to repeat the speech stimuli with 96.7% accuracy (SD 4.2%). The mean percent correct results for the 6- and 7-year-olds did not differ; however, the standard deviation for the 6-year-olds was more than twice the size of that for the 7-year-olds, indicating greater variability in performance for 6-year-olds.

This greater variability of younger school-aged children on tests of auditory processing is also seen in the normative data provided with the AUDiTEC™ Pitch Pattern Sequence (PPS) child version. This pitch pattern test has longer tone durations and longer inter-tone intervals than the more widely used FPT pitch pattern test (Musiek, 1994); hence, it is likely to be more suitable for young children. The mean percent correct score for the 6-year-olds is 82%, whereas for the 7-year-olds the mean percent correct score is 90%. Although these means only differ by 8%, the range of scores for 6-year-old children is much greater at 45-100% than the range for 7-year-olds at 60-100%. Increased variability in the performance of children 6 years of age on the PPS may be due to a lack of understanding for test instructions or insufficient training. The PPS was evaluated in the current study, with the addition of a training phase to see if this would improve inter-subject reliability. A Compressed and Reverberated Speech Test (CRST) and several subtests of a phonological/phonemic awareness assessment were also evaluated. By establishing whether these tests can be efficiently administered, and by determining what adjustments may be necessary to reduce inter-subject variability and ensure an appropriate level of difficulty, it is anticipated that the findings of this pilot study can be used as a basis for the development of a standardized test battery for the assessment of auditory processing in 6-year-old children. Therefore, the primary goal of the current study was to evaluate two tests of auditory processing and a test of phonological/phonemic awareness to determine if they could be administered efficiently and with acceptable inter-subject reliability to 6-year-olds.

Method

Participants

Testing was completed on 16 girls and 13 boys between the ages of 6;0 and 6;11 (years; months) who were recruited from three schools within the Auckland, New Zealand region. The children were recruited based on their age; therefore, their grade level varied across New Zealand's Years 1 and 2 (U.S. grade equivalent: Kindergarten through 2nd grade). The mean age of participants was 6; 6 (SD 3.19). Children were included in the study if they met the following criteria: (1) were typically developing and between the ages of 6;0 and 6;11; (2) did not currently have speech, language, hearing, or learning problems, or a history of speech, language or hearing problems, based on parental report; (3) used English as their main language for communication at home and at school; and (4) exhibited normal hearing and middle ear status at time of testing. Specific information concerning each child's speech, language, and hearing history was obtained from parents and caregivers by way of a short questionnaire. Several children were excluded based on the information provided by their parents or caregivers.

Materials and Procedure

All testing was performed in a quiet room at the participant's school. The level of ambient noise and/or external noise was measured at the beginning of all test sessions and was consistently less than 40 dB SPL. Each participant's hearing status was assessed before the administration of the test battery; participants' outer ear canals were examined via otoscopy. A tympanogram was obtained for each ear using a Grason-Stadler GSI-37 Auto Tymp to ascertain middle ear status. A hearing screening was conducted from octaves 250 to 8000 Hz at 15 dB HL using a Grason-Stadler GSI-61 clinical audiometer. ER-3A insert earphones were utilized for all audiometric and auditory processing assessments. Fifteen children were excluded from the study at this initial stage due to a failure on the middle ear screening (Type B or C tympanograms) or the hearing screening (one or more thresholds > 15 dB HL).

Each participant completed three assessments: the Queensland University Inventory of Literacy (QUIL; Dodd et al., 1996), the AUDiTEC™ PPS child version, and a Compressed and Reverberated Speech Test (CRST) developed at the University of Auckland. The order in which tests were administered was randomized. Each participant completed two, 30-minute test sessions. In the first session, participants underwent all peripheral audiological tests and completed one of the tests of (central) auditory processing or phonological/ phonemic awareness. In the second session, the two remaining assessments were administered.

The QUIL (Dodd et al., 1996) is an assessment tool developed and normed in Australia that is used clinically to assess phonological/phonemic awareness skills of children between the ages of 6 and 12 years. Five subtests of the QUIL (Dodd et al., 1996) were administered, including nonword reading (NWR), syllable identification (SI), spoken rhyme recognition (SRR), phoneme detection (PD), and phoneme manipulation (PM) and were administered in this order in accordance with the QUIL instruction manual (Sharma, Purdy, & Kelly, 2012). These subtests were selected to include stimuli that assess a range of phonological/phonemic awareness skills. Each subtest contains a set of instructions to be verbally presented and a set of practice items that are administered before the presentation of the test items.

The AUDiTEC™ PPS child version is a clinical tool that assesses the ability of young children to identify pitch (frequency) patterns. A pattern of three tones are presented monaurally. Each tone is 500 ms in duration and is either high frequency (H, 1430 Hz) or low frequency (L, 880 Hz). The interval between each tone in the pattern is 300 ms. There are six possible patterns (i.e., high-low-high [HLH], HHL, HLL, LHL, LLH, LHH) and three response modes that the child may use to indicate the perceived pattern, namely humming, verbal labeling, or pointing to a high/low visual. To eliminate tester-bias, the only response mode made available in this study was verbal labeling. Due to concerns about the ability of 6-year-olds to attend to an auditory-based assessment for extended periods of time, a shortened version of the AUDiTEC™ PPS child version was used, with only 15 items per list (one list per ear). Pitch patterns were presented at 60 dB HL through insert earphones via a Grason Stadler GSI-61 clinical audiometer and CD player. All children participated in a training phase prior to presentation of the test items. For the training phase, the clinician told the child what they would be hearing, which was either a high tone (1500 Hz) or a low tone (750 Hz), and then the tone was presented via the GSI-61 audiometer. Once the child could identify the tones in isolation, the clinician would present a two-pattern sequence via the audiometer (e.g., HL or LH) and ask the child to verbally label the pattern. Once the child could successfully label two tone patterns, the clinician would then present three tone patterns (e.g., HHL or LLH) via the audiometer. If a participant was having considerable difficulty identifying the patterns during the training phase, a high/low visual aid was introduced. The visual aid was removed before presentation of test items. Patterns that the child completely reversed (e.g., HLL reported as LHH) were noted for later analysis.

The CRST created for use in this study was composed of two lists of 25 words that were digitally compressed (65%) and reverberated (0.3 s) using Adobe Audition 1.5 software. The words included in each of the lists were taken from the Lexical Neighborhood Test (LNT; Kirk, Pisoni, & Osberger, 1995) easy word list and recorded using a female native New Zealand English speaker. All 60 items of the LNT (Kirk et al., 1995) easy word list were used, and then further divided into two lists of 25 words plus practice items. Each participant was presented with two words that were not compressed or reverberated before listening to practice items that were compressed and reverberated. Participants were instructed to repeat each word and were asked to guess the word if they were unsure of what they had heard. All practice and test items were presented at 60 dB HL through ER3A insert earphones via a GSI-61 clinical audiometer and a CD player. Both phonemic scoring and whole word (right/wrong) scoring were utilized and percent correct scores were calculated.

For the PPS and the CRST, both list order and ear order were counterbalanced and therefore, four list- and ear-order combinations were possible: (1) list one-left ear, list two-right ea; (2) list one-right ear, list two-left ear; (3) list two-left ear, list one-right ear; (4) list two-right ear, list one-left ear. The time taken to complete each of the tests, including instructions, was recorded for each child and rounded to the nearest 30 seconds. The average time taken for the QUIL was 15.5 minutes (SD 2.46; range 10 - 20), the average for the PPS was 10 minutes (SD 2.28; range 6.5 - 14), and the average for the CRST was 9 minutes (SD 2.50; range 5 - 15.5).

Results

Table 1 details the descriptive statistics for all three tests in the battery. Descriptive statistics are presented for both CRST scoring methods (i.e., whole word and phonemic) and for PPS scores, both including and excluding reversals. Performance was variable across and within the tests. In general, the CRST results (when scored phonemically and by whole words) showed the least variability. However, PPS results showed similar variability when reversals were considered correct. Data are presented here with reversals included and excluded for comparison. In general, mean and median test scores agreed within 7% for each of the subtests and lists. However, for the QUIL NWR subtest of the mean percent correct score was almost 17% greater than the median, suggesting that the performance of a few children skewed the data towards a higher average score.

Auditory Processing Tests (Pitch Pattern Sequence and Compressed and Reverberated Speech Test)

List effects. Paired samples t-tests were conducted to determine whether there were significant differences in performance on the two lists of the PPS and the CRST. There was a significant list difference for the PPS when reversals were excluded (Table 2). Participants scored an average of 74.9% (SD 18.6%) on list one and 69.4% (SD 20.5%) on list two. There was no significant difference between PPS lists when reversals were included.

Due to the significant differences in participants' performance on the two PPS lists (excluding reversals), participants' ability to correctly identify the various pitch patterns was investigated. Table 3 displays the distribution of the patterns across the PPS lists and overall percent correct scores for each of the patterns. The LLH pattern was easiest for participants to identify, followed by the HHL pattern. These two patterns occurred more in list one than in list two. The LHL and the LHH patterns were the hardest pattern for participants to identify. Patterns were unevenly distributed between the lists.

Performance across CRST lists was also significantly different for both scoring methods. Participants scored an average of 33.9% (SD 11.9%) and 39.7% (SD 10.9%) for lists one and two (whole words), respectively. Overall, participants scored better when responses were scored phonemically. Average phoneme scores were 54.9% (SD 10.7%) for list one and 66.0% (SD 8.4%) for list two.

Test item effects were investigated because of the CRST list differences. Table 4 presents whole word percent correct values for each of the CRST test items. Several of the words were correctly identified by almost all of the participants (e.g., 'please' and 'just'). Equally, several words were not correctly identified by a single participant (e.g., 'kind' and 'brought').

Ear effects. Possible differences between left-ear and right-ear scores for both the CRST and the PPS were investigated by means of independent *t*-tests. There was a small right ear advantage for both lists of the PPS and list one of the CRST; however, as illustrated in

Table 1. Descriptive statistics (presented as percent values) for the Queensland University Inventory of Literacy (QUIL), the Pitch Pattern Sequence (PPS) and the Compressed and Reverberated Speech Test (CRST)

Test	Subtest or List	Min.	Max.	Median	Mean	SD
QUIL	NWR	0	95.8	16.7	33.5	32.5
	SI	33.3	100	83.3	78.4	18.3
	SRR	50.0	100	83.3	77.6	17.1
	PD	8.3	91.7	50.0	53.2	22.5
	PM	0	100	60.0	53.8	29.9
PPS – R	List 1	40.0	100	80.0	74.9	18.6
	List 2	26.7	100	73.3	69.4	20.5
PPS + R	List 1	53.3	100	93.3	87.8	12.6
	List 2	66.7	100	86.7	85.5	11.3
CRST WWS	List 1	8.0	52.0	28.0	33.9	11.9
	List 2	20.0	68.0	40.0	39.7	10.9
CRST PS	List 1	32.1	75.2	54.1	54.9	10.7
	List 2	43.4	79.8	66.7	66.0	8.4

Note: WWS (whole word scoring), PS (phonemic scoring), – R (excluding reversals), + R (including reversals), NWR (nonword reading), SI (syllable identification), SRR (spoken rhyme recognition), PD (phoneme detection), PM (phoneme manipulation), SD (standard deviation). The QUIL descriptive statistics were calculated using raw score data rather than standard scores.

Table 2. *t*-test results for list, ear, reversal, and scoring effects on Pitch Pattern Sequence (PPS) and Compressed and Reverberated Speech Test (CRST) scores

Test	List	Effect	*t*	Df	Sig. (2-tailed)
PPS		List (- R)	2.74	28	0.011
		List (+ R)	1.63	28	n.s.
	List 1	Ear	-0.36	27	n.s.
	List 2	Ear	-0.92	27	n.s.
	List 1	Reversal	-5.30	28	<0.001
	List 2	Reversal	-5.71	28	<0.001
CRST		List (WWS)	-3.65	28	0.001
		List (PS)	-6.36	28	<0.001
	List 1 (WWS)	Ear	-0.29	27	n.s.
	List 2 (WWS)	Ear	1.74	27	n.s.
	List 1 (PS)	Ear	-0.77	27	n.s.
	List 2 (PS)	Ear	1.93	27	n.s.
	List 1	Scoring	-29.17	28	<0.001
	List 2	Scoring	-20.26	28	<0.001

Note: WWS (whole word scoring); PS (phonemic scoring); - R (excluding reversals); + R (including reversals); n.s. indicates p>.05.

Table 3. Percent correct scores across participants (N=29) for words in both lists of the CRST ordered from highest to lowest

List one		Percent correct	List two		Percent correct
(6)	Truck	82.8	(6)	Please	96.6
(13)	Friend	75.9	(15)	Just	96.6
(19)	Wash	72.4	(25)	Watch	89.7
(12)	School	58.6	(12)	Seven	89.7
(23)	Little	55.2	(21)	Which	86.2
(11)	Finger	55.2	(20)	Food	69.0
(7)	Children	48.3	(5)	Pocket	58.6
(4)	Stand	37.9	(14)	Street	51.7
(15)	Lipstick	37.9	(2)	First	51.7
(10)	Broke	34.5	(9)	Don't	31.0
(18)	Juice	31	(17)	Shoelace	31.0
(24)	Snake	27.6	(8)	Puzzle	27.6
(25)	Open	24.1	(22)	Space	27.6
(17)	Monkey	24.1	(23)	Black	27.6
(22)	Draw	20.7	(24)	Its	27.6
(20)	Ducks	17.2	(13)	Eggs	27.6
(21)	Myself	17.2	(7)	Help	24.1
(8)	Cried	13.8	(4)	Stay	24.1
(16)	Give	13.8	(18)	Wonder	24.1
(9)	Farm	6.9	(16)	Grey	10.3
(2)	Airplane	3.4	(3)	String	10.3
(3)	Brown	3.4	(10)	Scribble	6.9
(1)	Kind	0	(1)	Green	3.4
(14)	Thinks	0	(11)	Door	0
(5)	Broken	0	(19)	Brought	0

Note: Numbers in parentheses indicate test item numbers.

Table 4. Distribution of pitch patterns (30) across the lists of the Pitch Pattern Sequence (PPS) and percent correct scores across participants (N=29) for each of the pitch patterns

	HLL	LHH	LHL	HLH	HHL	LLH
List 1	1	1	2	4	4	3
List 2	1	3	2	4	3	2
Percent correct	65.5	64.7	55.2	71.1	79.3	82.8

Note: HLL (high-low-low), LHH (low-high-high), LHL (low-high-low), HLH (high-low-high), HHL (high-high-low), LLH (low-low-high).

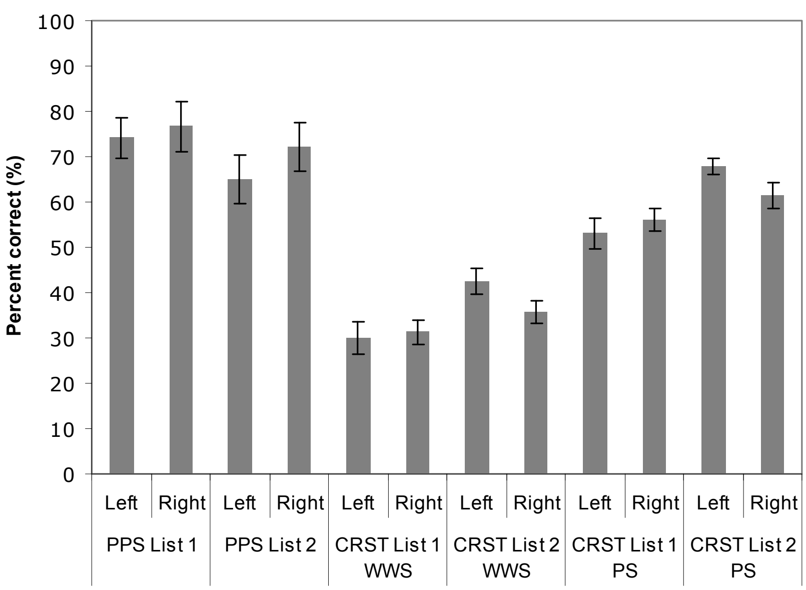

Figure 1. Mean percent correct scores for list one and two of the Pitch Pattern Sequence (PPS; excluding reversals) and the Compressed and Reverberated Speech Test (CRST) according to the ear in which the lists were presented. Mean percent correct scores for both scoring methods of the CRST are presented. Error bars indicate ±1 standard error.

Figure 1 and Table 2, no significant differences were found between the participants' left- and right-ear performance on either list of the PPS or CRST.

Scoring effects. A paired samples *t*-test was conducted to determine whether mean list scores for the PPS were significantly different when reversals were added to the final score. Both list one and list two scores were significantly better when reversals were considered correct and included in the final score (Table 2).

The two lists of the CRST were scored phonemically and by whole words. Paired samples *t*-tests showed a significant difference between mean percent correct scores according to scoring method for both CRST lists (see Table 2). For list one, the average whole words percent correct score was 33.9% (SD 11.9%) and the mean phonemic percent correct score was 54.9% (SD 10.7%). For list two the means were slightly higher. The average whole words percent correct score was 39.7% (SD 10.9%) and the mean phonemic percent correct score was 66% (SD 8.4%).

Phonological Assessment (Queensland Inventory of Literacy)

The QUIL raw scores were converted to standard scores using the normative data provided in the QUIL test manual. As these normative data are grouped according to school year (e.g., grade one, grade two etc.), the data obtained in this study were not directly comparable to the normative data of the QUIL. The mean age of the grade one QUIL sample was 6; 3 (years; months) and the mean age of the grade two QUIL sample was 7; 2. Neither grade level sample age was identical to the mean age (6; 6) of the sample in the current study, and, hence, the raw scores were converted to standard scores using both grades one and two normative data, depending on the age of the individual child. The QUIL standard score mean was 10 (SD 3).

As shown in Figure 2 participants performed better than the QUIL normative data for the grade one sample, but poorer than the grade two sample on all five subtests. Overall, participants performed best on the NWR and the PM subtests. However, the range of scores for these subtests, particularly NWR, was relatively large. Participants performed poorest on the SRR and PD subtests and these subtests both had a large range of scores. Performance was most consistent for the SI subtest.

Discussion

All children were able to complete all tests and the average time for each test was approximately 10-15 minutes including instruction and practice. Thus, in general, the QUIL, PPS, and CRST can be efficiently administered to 6-year-old children. Performance was quite variable, however, and several modifications are recommended to reduce variability between items, lists, and participants.

Pitch Pattern Sequence

Participants in the current study were less variable on this assessment (when reversals were included as a correct response) than the children in the AUDiTEC™ PPS 6-year-old sample. Thus, the training phase may have enhanced inter-subject reliability. Participants showed no ear effects on the PPS, but a small right ear advantage (REA) was noted. This is consistent with other data obtained for pitch pattern tests (Bellis, 2003; Kelly, 2007). Kelly (2007) found a slight REA in the FPT for the youngest age group (7- and 8-year-olds).

A list effect was observed when reversals were excluded. The difference in distribution of the pitch patterns across the lists and variations in pattern difficulty are likely to have caused this list difference. Two patterns were clearly easier for the participants to identify, namely HHL and LLH. On the basis that the first two tonal stimuli are identical (i.e., HH and LL) in both of these patterns, memory may have had an impact on the participants' performance. Recall of the first two stimuli in these patterns would be reinforced by repetition of the same tonal stimulus. The memory trace for the high or low tone would be strengthened by the repetition of the stimulus (Haenschel, Vernon, Dwivedi, Gruzelier, & Baldeweg, 2005), allowing the participants to confirm their judgment of the first tone and more easily distinguish the first two tones from the final tone.

There was no list effect when reversals were scored as correct. A possible explanation for this is that participants reversed several of the harder items and when these were included in the final score, the difference between the list means was not as great. In order to eliminate list differences, future PPS lists should contain equal numbers of each pattern in lists. Reversals should be recorded so that results can be compared with and without reversals in typically developing children versus children with suspected (C) APD to determine the diagnostic utility of the scoring methods for this population.

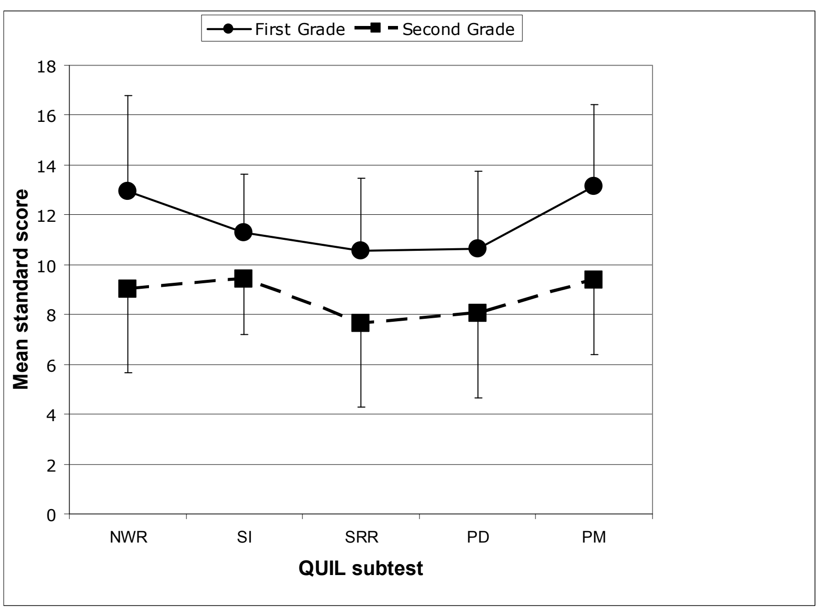

Figure 2. Mean standard scores for the nonword reading (NWR), syllable identification (SI), spoken rhyme recognition (SRR), phoneme detection (PD), and phoneme manipulation (PM) subtests of the QUIL. The upper line shows the mean standard score calculated using the grade one standardization data, and the lower line shows the mean standard scores calculated using the grade two standardization data. Error bars indicate ±1 standard deviation.

Compressed and Reverberated Speech Test

Performance was least variable across participants on the CRST and variability of scores was similar for phonemic and whole word scoring. As anticipated, scores were higher when calculated using phonemic scoring, but this was a difficult task. While phonemic scoring gives credit to an examinee for each phoneme repeated correctly (rather than simply marking something correct versus incorrect) it requires that the clinician be experienced in phonemic scoring. Unfortunately, the words used to create the CRST were not equally identifiable when compressed and reverberated due to the distortion that occurs when a word is digitally compressed and reverberated. The LNT easy words used in this assessment are words with a high frequency but few lexical neighbors (i.e., words that differ by only one phoneme; Kirk et al., 1995). According to the British National Corpus the test words vary in frequency from 6 to

1632 per million words (Leech, Rayson, & Wilson, 2001). Words in the test lists that had a greater frequency, based on the British National Corpus, were not necessarily easier for the participants to identify, and therefore lexical frequency does not appear to have had a substantial impact on the performance. The acoustic properties of the sounds contained within the words are likely to have had the most significant impact on how identifiable the words were once they were compressed and reverberated. However, determining the impact of acoustic distortion versus lexical frequency on word accuracy is difficult. In general, the words that were correctly identified contained fricatives (e.g., ‘s’), affricates (e.g., ‘j’), liquids (e.g., ‘r’), and glides (e.g., ‘w’). It may be that particular sounds are more susceptible to the effects of distortion (compression/reverberation) than other words. Future use of this assessment should be performed using lists better matched for word difficulty after the words are compressed and reverberated.

Queensland University Inventory of Literacy

The NWR subtest was the most difficult of the QUIL subtests and this subtest also demonstrated the greatest variance. Participants demonstrated the highest scores and the least variability on the SI and SRR subtests. The variability participants demonstrated across QUIL subtests may be due to two factors. The first factor is variation in reading instruction. A phonics approach to reading instruction involves the teaching of letter sounds to facilitate the decoding of unfamiliar words (Vellutino, 1991). In contrast, whole word and whole language approaches to reading encourage children to identify words as a whole and use the immediate context of an unfamiliar word to facilitate meaning (Vellutino, 1991). Participants who learned to read primarily or solely via a phonics approach may be more successful at thinking about the sounds and sound parts that make up words than those who have taught to read by means of a whole word or a whole language approach. Children in New Zealand may be taught using one or both of these approaches. Figure 2 shows that, if grade two norms are used, performance was close to the norm and was reasonably consistent across PD, SRR, and SI subtests. This suggests that these skills may be less influenced by variations in reading instruction between children. A reduced set of QUIL assessments including these three subtests would assess a range of phonological awareness skills with acceptable inter-subject variability, at least for the sample of children in the current study.

Summary

The accurate identification of children with (C)APD requires a multi-professional approach (Witton, 2010). Unfortunately, the diagnosis of pure (C)APD is rare; therefore, it is important to incorporate additional tests of speech and/or language in the comprehensive evaluation for (C)APD (Sharma, Purdy & Kelly, 2009; Witton, 2010). Due to the complexity of the brain and the global impact of developmental disorders, this study included tests of both auditory and phonological/phonemic processing in the evaluation for (C)APD.

The performance of 29 typically-developing 6-year-olds on an auditory and phonological/phonemic processing test battery was examined. The test battery consisted of the PPS, CRST, and QUIL. With some modifications, all three tests can be efficiently administered to 6-year-old children. For the PPS, the lists should be modified so that they contain equal numbers of each type of pattern. The lists in the CRST should be reorganized so that they consist of words with more evenly matched difficulty. Because of the influence of literacy education on phonological/phonemic awareness results, normative results for QUIL subtests are likely to vary between educational systems and hence more research is needed to establish the link between auditory processing and phonological awareness in young children. The sample size of the current study was relatively small, yet comparable to those of several other studies examining the performance of young children on tests of auditory processing (Keith, 2002; Stollman et al., 2004a; Stollman et al., 2004b). Further research is needed to establish the inter-subject and test-retest reliability of tests of auditory processing in large groups of younger children (less than 7 years of age). Once reliable measures are established, the sensitivity of these measures to (C)APD should be assessed.

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