Title of the Project: Maturation of Auditory Processes in Children aged 6 to 10 years

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Abstract

In order to diagnose auditory processing disorders (APD), it is essential to have valid age appropriate normative data on a battery of tests. With this in focus, the present study aimed to establish normative data on a battery of tests. The tests included 'Speech perception in noise in Indian English' (SPIN-IE), 'Dichotic Consonant Vowel' (DCV), 'Duration pattern test' (DPT) and the 'Revised auditory memory and sequencing test in Indian English' (RAMST-IE). Normative data were collected from 280 typically developing children in the age range of 6 years to 10 years, 11 months. The children, who were divided into five age groups, were found to have enhancement in scores with increase in age. However, the quantum of improvement varied from test to test. The youngest age group was able to carry out all the tests except the DPT. A marked difference in performance between the ears was observed for the DCV test only in the youngest and oldest age groups. This was not seen in the middle three age groups. On all four tests, no significant difference was found between the boys and girls across all five age groups.

Based on the findings of the children having symptoms of APD, a cut-off criterion of 2 SD below mean of typically developing children was recommended to diagnose children as having APD if they performed poorly only one test in the battery. However, for children performed poorly in more than one test on the APD test battery, it was recommended that a cut-off criterion of 1 SD below the mean of typically developing children be used.

1. Introduction

Processing of auditory signals are reported to require several auditory abilities or skills. These include sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition such as temporal integration, temporal discrimination (e.g. temporal gap detection), temporal ordering, temporal masking, as well as auditory performance with degraded acoustic signal [American Speech Hearing Association, (ASHA) 2005]. A deficit in any of these processes has been found to result in an auditory processing disorder (APD). It has been observed that children experiencing listening difficulty have poor academic performance (Chermak, & Musiek, 1992; Emerson, Crandall, & Chermak, 1997; Dawes, & Bishop, 2007). Further, children with APD have been found to have poor self-esteem (Keller, 1998; Keith, 2000a; Bellis, 1996), logic problems (Bellis, 1996) and difficulty in social interactions (Willeford, 1985).

Due to the heterogeneity seen in children with APD, the use of a test battery has been recommended (Barren, 2007). In several studies, deficiency in one or more processes has been noted in children with APD (Welsh, Welsh & Healy, 1980; Musiek et al, 1982; Katz, Kurpitha, Smith & Brandner, 1992; Muthuselvi & Yathiraj, 2009). Though it is an established fact that a test battery approach is superior to isolated tests, there is considerable debate among audiologists regarding the choice of tests to be incorporated in a tests battery (Musiek &, Chermak, 1994; Keith, 1996; ASHA, 1996, 2005). The sensitivity and specificity of a test battery has been found to differ depending upon the tests used in the assessment process. However, there is no gold standard presently available for the choice of tests in the test battery approach.

The earlier test batteries focused on identifying site-of-lesion and the tests chosen focussed on assessing central auditory nervous at different levels. One such battery by Willeford (1977) included a binaural fusion task to assess the brainstem, and filtered speech to test the lower level functioning of the temporal lobe. The battery also included a dichotic listening task to evaluate the function of the temporal lobe and higher levels of the central auditory pathway.

In literature, variations in the choice of tests to be included in an APD test battery have been reported (Katz, Kurpitha, Smith, & Brandner, 1992; ASHA, 1996, 2005; Baran, & Musiek, 1999; Chermak, & Musiek, 1997; Jerger & Musiek, 2000; Bellis, 2003). Katz et al. (1992) recommended a test battery consisting of the staggered spondaic word test, the phonemic synthesis test and the speech-in-noise (SPIN) test to evaluate a cluster of four auditory behavioural characteristics of APD. The processes evaluated using the test battery were decoding, tolerance-fading memory, integration and organisation. However, they recommended that other tests need to be administered based on a client's complaints and the results of the test battery.

Several investigators recommend a battery that includes dichotic speech tests, monaural low redundancy speech tests, temporal patterning and binaural interaction tests (Bellis, 1996, 2003; Chermak & Musiek, 1997; Hall & Mueller, 1997; Baran, 2007). Musiek and Chermak (1995) suggested that the first order diagnostic tests should include the dichotic digit test, dichotic sentence test, and one of the temporal ordering tests such as frequency pattern test or the duration pattern test (DPT) in case of adults. The second order tests that were suggested included Middle latency response, Staggered Spondee Word test, Tallal's ordering test, the dichotic rhyme test and time compressed speech. While, this battery includes many tests in the dichotic mode, it does not test auditory memory. Medwetsky (1994) advocated testing a span of apprehension, decoding ability, short-term memory retention, auditory linguistic integration, sequencing and auditory attention. This battery however did not assess binaural integration.

A report of the ‘Consensus Conference on the Diagnosis of Auditory Processing Disorders in School-Aged Children’, Jerger and Musiek (2000) detailed that a test battery for APD should include three areas: a dichotic task (e.g., dichotic digits, dichotic words, or dichotic sentences) to tap auditory processing; Duration pattern sequence test to detect auditory temporal processing; and Temporal gap detection to measure auditory temporal processing. These behavioural tests were recommended besides evaluating the performance-intensity functions for word recognition. Monaural low redundancy tests were not included in this battery.

ASHA (2005) recommended that the diagnosis of a central auditory processing disorder should be accomplished using a variety of indices, including case history, non-standardized but systematic observation of auditory reference and audiological test procedures. In addition, ASHA listed several categories of auditory measures to serve as a guideline for audiologists regarding the available tests. The measures included auditory discrimination of frequency, intensity and/or duration; tests of temporal processes and temporal patterning; dichotic speech tests to evaluate integration or separation; monaural low-redundancy speech tests (time compressed, filtered, interrupted, competing, etc); and binaural interaction tests; electroacoustic measures (Oto Acoustic Emissions, acoustic reflex thresholds, acoustic reflex decay); and electrophysiological procedures (Auditory Brainstem Responses, middle latency response, 40 Hz response, steady-state evoked potentials, frequency following response, cortical event-related potentials [P1, N1, P2, P300], mismatch negativity, topographical mapping). Although this test battery is comprehensive one, it failed to evaluated auditory memory and sequencing.

Yathiraj and Mascarenhas (2003) evaluated children with suspected APD using SPIN test, DPT, dichotic consonant vowel (DCV), auditory memory and sequencing test. The results revealed that children who were identified as having APD did not show identical processing deficits. Hence, they recommended using various tests to profile each child which would further help in further management. Muthuselvi and Yathiraj (2009) used a test battery which assessed monaural auditory separation / closure (SPIN), binaural integration (DCV), binaural interaction (Masking Level Difference), temporal resolution (Gap Detection Test), and auditory memory and sequencing. Similar to the earlier observation of Yathiraj and Mascarenhas (2003), it was noted that there was heterogeneity in the performance of the children on the APD tests. Hence, they too stressed the importance of using a battery of tests to assess different auditory processes. In addition, it was found that the children had greater problems with binaural integration and auditory memory, followed by auditory separation / closure and temporal resolution. Based on this information it was suggested that the processes that are affected more frequently should be given priority, if there was a time constrain in evaluating all processes.

Thus, the review of literature suggests the need for a test battery approach in the assessment of APD. A number of factors have been found to affect the results of tests used for assessing auditory processing and an important one among them is the maturation of auditory processes.

The maturation of auditory processing are reported to follow the course of neuromaturation (Bellis, 1996). Romand (1983) noted that a variety of age-dependent morphological changes occurred in the brain and influenced auditory behaviour, the most prominent of which was the degree of myelination. Earlier researchers had reported that myelination proceeded in caudual to rostal direction, with the structure of the brainstem necessary for survival completed before the first year of age where as cortical communication areas were not fully myelinated until early adulthood (Yakovlev & Lecours, 1967). Bellis (1996, 2003) observed that the differences in the time and rate of myelination of various areas of the brain development would have considerable impact on auditory processing, as the processes that depend upon brainstem function would develop much earlier than those that relay upon efficient inter- and intra-hemispheric communication. Hence, Bellis opined that age related morphological changes within the brain would determine the ability of children to perform certain auditory tasks. Based on this it was considered mandatory that clinicians engaged in central auditory assessment be familiar with normal variations in the development of the central nervous system in order to select the most appropriate tools, interpret test results in the context of age appropriate normative data, and develop management plans based on the stage of neuro-audiological development. Table I.1 provides a summary of the neuromaturational course of different auditory processes as reported by Bellis (2003) and Whitelaw and Yuskow (2005). These reports were based on past research. Whitelaw and Yuskow (2005) as well as Bellis (2003) agreed that different auditory processes takes different maturational courses.

Table I.1: *Neuro-maturational courses of auditory processes according to Whitelaw and Yuskow (2005)and Bellis (2003)*

Auditory processes	**Neuro-maturational courses**	
	Whitelaw and Yuskow (2005)	***Bellis (2003)***
Hearing-in-noise	Improvement seen from 10 to 11 years depending on the listening situation.	Have not specified the maturation course.
Dichotic listening	Maturation noted up to 9 to10 years, but task specific skills develop until adolescence.	Overall performances improved up to 12 to 13 years. REA improved up to 10 to 11 years, but it depends on linguistic load of the stimuli.
Binaural	Reaches adult values between 6 to 8	Precision or accuracy of

interaction	years, but could be task specific.	localization occurs at 5 years.
Temporal processing	Appears to reach adult like performance between 10 to 12 years.	Temporal patterning tasks reaches adult like values by 12 years. Temporal resolution abilities improve until 8 to 10 years.

Keith (1995, 2000b) suggested that the auditory system of normally developing individual was typically mature by the age of 12 years. However, speech-in-noise processing was found to not show a clear maturation from the age of 6 years. Similar finding were also reported by Amos and Humes (1998).

Neijenhuis et al. (2002) found that auditory processing developed until 9 to 12 years. They also found that word-in-noise did not show significant maturational effects. On the other hand, the sentence-in-noise test showed age effect from 14 years until adulthood.

Stollman, Velzen, Simkens, Snik and Broek (2004) investigated the development of auditory processes in children aged 6 to 12 years. Their test-battery consisted of a speech-in-noise test, a filtered speech test, an auditory synthesis test, an auditory closure test and a number recall test. They observed that tests were independent of each other and assessed different auditory processes. Thus, the finding indicated that each test contributed equally to the test battery. They also found that the entire test battery showed maturational effects up to 12 years, except the speech-in-noise test.

In a similar study, Stollman, Neijenhuis, Jansen, Simkens, Snik, and Broek (2004) demonstrated that APD tests could be carried out effectively in children as young as 4 years of age. Children in the age range of 4 to 6 year were tested using a test battery consisting of a sustained auditory attention test, a dichotic words test, a binaural masking-level difference test, an auditory word discrimination test, a gap detection test and a test of phonemic awareness. The older children were found to perform better than the younger children with the difference being most prominent for the dichotic word test and the phoneme awareness test. The 4-year-old and the 6-year-old children had a small, but significant right-ear advantage on the dichotic test, which was absent in the 5-year-olds. They observed no difference between their male and female participants. They also found a correlation between most of the tests that they studied and this was attributed to the similarity of the auditory abilities being evaluated by the tests.

To tap different processes a variety of non-Indian (Table I.2) as well as Indian tests (Table I.3) have been developed. These tests, evaluated on different age groups demonstrate that the different auditory processes have distinct maturational courses.

Table I.2**:** *List of a few Non-Indian tests for APD and the process assessed*

Name of the Tests & Authors	**Process assessed**
Staggered Spondaic Word test (Katz, & Ivey, 1994)	Binaural integration
Competing Sentence Test (Willeford, & Burleigh, 1994)	Binaural integration
Auditory Continuous Performance Test (Keith, 1994)	Attention
Dichotic digits (Kimura, 1966 revised by Muisek, 1983)	Binaural integration
Dichotic consonant vowels (Berlin et al., 1972)	Binaural integration
Dichotic sentence identification test (Fifer et al., 1983)	Binaural integration
Dichotic rhyme test (Wexler & Halwes, 1983)	Binaural integration
Frequency pattern test or Pitch pattern sequence test (Pinheiro &	Temporal ordering/patterning

Ptacek, 1971)	
Duration pattern test (Pinheiro & Musiek, 1985)	Temporal ordering/patterning
Psychoacoustic pattern discrimination test (Blaettner et al., 1989)	Temporal discrimination
Random gap detection test (Keith, 2000)	Temporal resolution
Gap-in-noise test (Musiek et al., 2005)	Temporal resolution
Low pass filtered speech (Bocca, Calearo, & Cassinari, 1954) Low-Pass filtered Speech test (Wileford, 1976)	Auditory closure
Time compressed speech (Keith, 2002)	Auditory closure
Synthetic speech identification with ipsilateral competing message (Jerger & Jerger, 1974, 1975) Synthetic speech identification with contralateral competing message (Jerger & Jerger, 1974, 1975)	Auditory closure
Speech-in-noise test (Olsen, Noffsinger & Kurdziel, 1975)	Auditory closure
Time compressed plus reverberation (Wilson et al., 1994)	Auditory closure
Rapidly alternating speech perception (Willeford & Bilger, 1978)	Binaural interaction
Masking level differences (Hall & Grose, 1990)	Binaural interaction
Binaural fusion Test (Willeford & Bilger, 1978)	Binaural interaction

Interaural Just Noticeable difference (Pinheiro & Tobin, 1971)	Binaural interaction
Listening in spatialized noise – software (Cameron & Dillon, 2009)	Binaural interaction

Table I.3: *List of a few Indian tests for APD and the age groups for which norms are available*

Central auditory tests	Age Group	Process assessed
Dichotic CV test revised-Normative data on children (Krishna & Yathiraj, 2001)	7 to 11 years	Binaural integration
Dichotic CV test revised-Normative data for adults (Prachi & Yathiraj, 2001)	18 to 30 years	Binaural integration
Time compressed speech test in English for children (Sujitha & Yathiraj, 2005)	7 to 12 years	Auditory closure
Duration pattern test (Gouri & Manjula, 2003)	8 to 12 years and >18 years	Temporal patterning / ordering
Gap detection test (Shivaprakash & Manjula, 2003)	7 to 12 years and >18 years	Temporal resolution
Pitch pattern sequence test (Shivani & Vanaja, 2003)	9 to 10 years and adults	Temporal patterning/ ordering
Temporal modulation transfer function (Kumar & Sangamanatha, 2011)	20 to 85 years	Temporal resolution
Binaural fusion test in English for children (Shivaprasad & Yathiraj, 2006)	7 to 12 years	Binaural interaction
Auditory memory test in English (Yathiraj & Mascarenhas, 2003)	7 to 12 years	Auditory memory
Auditory memory test in Kannada (Yathiraj and Vijayalakshmi, 2005)	6 to 12 years	Auditory memory

Synthetic Sentence Identification Test in Hindi (Balvalli and Bantwal, 2011)	18 to 40 years	Auditory closure

An important component of any diagnostic test-battery for APD is the *criteria for diagnosing an individual* as having APD. The criteria used to label an individual as having APD, varies from study to study (Chermak & Musiek, 1996; Bellis & Ferre, 1999; Jerger & Musiek, 2000; Keith, 2000 b) and various monitoring organisations / associations (ASHA, 1996, 2005; AAA, 2010, British Society of Audiology, 2011). The ASHA task force on central auditory processing consensus development (1996), labelled a child as having APD if deviant performance was measured on one or more of the processes mentioned in their definition. These processes included sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance decrements with competing acoustic signals and auditory performance decrements with degraded acoustic signals. The ASHA working group on auditory processing disorders in 2005, continued to maintain the criterion of the 1996 task force. However, based on the findings of Chermak and Musiek (1997), they recommended that the individual should be diagnosed as having APD if the performance was at least two standard deviations below the mean on two or more tests in the battery. Additionally, they recommended that an individual could be labelled as having APD based on a single test " ---- unless the client's performance falls at least three standard deviations below the mean or when the finding is accompanied by significant functional difficulty in auditory behaviours reliant on the process assessed. Moreover, the audiologist should re-administer the sole test failed as well as another similar test that assesses the same process to confirm the initial findings" (pp 10/2005).

Similarly, based on the findings of earlier published research (Musiek et al., 2005; Shinn & Musiek, 2007; Turner & Hurley, 2009; Spaulding, Plante, & Farinella, 2006), the AAA task force (2010) stated "--- the use of cut-off scores that are based on appropriate normative data can be used. Cut-off scores (e.g., in percent correct, percentiles, or standard scores) are set at performance levels (e.g., ~ -2 standard deviations below the mean) to achieve the best balance between hit rate (sensitivity) and correct rejection rate (specificity)" (pp 15). The BSA (2011), in their position statement on APD, did not give any direct criterion to be used to diagnose an individual as having APD. Thus, it can be observed from the literature that there is no consensus regarding the criterion that should be used to diagnose whether an individual has APD or not.

The impact of having varied criteria to label a child as having APD was studied by Wilson and Arnott (2012). They analysed the files of 150 children who had been assessed for APD using four different tests (low pass filtered speech, competing sentences, two-pair dichotic digits, & frequency patterns with linguistic and non-linguistic report). They found that the children with normal peripheral hearing in the age range of 7.0 to 15.6 years were categorised as having or not having APD depending on the diagnostic criteria used. Using nine different criteria that were reported in the literature, they found that a stringent criterion (failure on any tests as per the primary APD sub-profiles offered by Bellis, 2003) resulted in 7.3% being diagnosed as having APD. In contrast, a lenient criterion (≥1 test at least monaurally within ≥1 auditory processing domain; ASHA, 2005) resulted in 96.0% of the children being diagnosed as having the condition. The study shed light on the need for a consensus regarding the criteria to be used while diagnosing APD.

From the literature on maturation of auditory processes, it can be seen the processes do not mature in a similar manner. Since different auditory processes matures at different rates, it is essential that a test battery should be age specific, as recommended by Bellis (1997, 2003). However, it can be seen from the studies mentioned in literature that the maturational pattern varies from one study to another. This variation can be attributed to the difference in stimuli used or procedural variations. Further, the studies carried out in India have been done on small participant groups. Due to this small number, classifying individuals as being deviant or not based on values provided in the studies is questionable. Hence, there is a need to establish age based norms on a large population on a battery of tests for APD. Thus, the study aimed to establish norms on a battery of tests that tapped monaural separation / auditory closure, binaural auditory integration abilities, temporal processing abilities as well as auditory memory and sequencing abilities in children aged 6 to 10 years. Additionally, the study aimed to determine the maturational changes for each of the auditory processes and compare them. Further, based on the performance of children with symptoms of APD, the study aimed to determine cut-off scores to diagnose the condition.

2. METHOD

In order to study the effect of maturation in children aged 6 to 10 on an APD test battery and to obtain normative data, 280 children were evaluated. The APD battery consisted of four different tests that tapped different auditory processes / cognitive ability associated with auditory processing, reported to be frequently affected in children having APD. The four tests evaluated monaural auditory separation / closure, binaural auditory integration, temporal patterning, and auditory memory. These aspects of auditory processing were selected since in the literature they have been noted to be more frequently affected in children with APD. In individuals with APD, auditory separation / closure was reported to be affected by Welsh, Welsh, and Healy (1980), Katz et al., (1992) and Muthuselvi and Yathiraj (2009); binaural auditory integration by Musiek et al, (1982), Katz et al, (1992) and Muthuselvi and Yathiraj (2009); and temporal resolution by Musiek et al, (1982) and Muthuselvi and Yathiraj (2009). Additionally, Muthuselvi and Yathiraj (2009) found that in 82.3% of the children studied by them, auditory memory was affected, making it the highest problem among the five auditory abilities evaluated by them.

The study was carried out in three phases; The first phase involved the development of tests for the APD test-battery that were not available; the second phase entailed the administration of the APD test-battery on typically developing children to obtain data on the maturation of auditory processes; and in the third phase the efficacy of the APD test battery was determined by administering it on children with suspected APD.

Participants

Two groups of participants were studied, one having no symptoms of APD and the other with symptoms of the condition. They were categorized into the two groups based on an APD screening checklist. The data collection was obtained in two different centres having similar test facilities, one located in Mysore and the other in Pune. The number of boys and girls tested in the two participant groups as well as within each age group was the same in both the centres.

Group-1 consisted of 280 school-going children in the age range of 6 years to 10 years. Children 'not at-risk' for APD, based on the 'Screening Checklist for Auditory Processing' (SCAP) developed by Yathiraj and Mascarenhas (2003, 2004) were included in this group. The checklist was answered by a teacher other than a second language teacher, who had taught the children curricular subjects for at least one year. The second language teachers were excluded as it was observed that they judged children as having a problem due their poor performance in a second language that was often not use by the children outside the classroom. In order to be considered 'not at-risk', the participants were required to have a cut-off score of less than six, as recommended by Yathiraj and Mascarenhas (2003, 2004) and Muthuselvi and Yathiraj (2009). This cut-off value had been found to result in an optimum sensitivity as well as specificity.

The children were categorized into four sub-groups based on their age. The youngest age group had 40 children and the four remaining age groups had 60 children each. The age groups had equal number of males and females (Table M.1).

Table M.1: *Age and gender distribution of the children who passed SCAP (Group-I)*

Age Range	No of children	Gender	
		Male	Female
6 to 6;11 years	40	20	20
7 to 7;11 years	60	30	30
8 to 8;11 years	60	30	30
9 to 9;11 years	60	30	30
10 to 10;11 years	60	30	30

Further, the children in both groups had average or above average IQ on the Raven's Progressive Coloured / standard Matrices (Raven, 1952). All the children included in both groups attended schools where the instruction was in English. The children were proficient in English, as reported by their teachers. Only those children with air conduction and bone conduction thresholds less than 15 dB HL in the octave frequencies 250 Hz to 8 kHz and 250 Hz to 4 kHz respectively, were included in the study. To confirm the presence of normal middle ear functioning, the participants were required to obtain 'A' type tympanograms with ipsi and contralateral acoustic reflexes present for the frequencies 500 Hz, 1 kHz and 2 kHz. In addition, speech identification scores in quiet, determined using the 'Common Speech Discrimination Test for Indians' (Mayadevi, 1974), were obtained for all the participants. This test with 25 nonsense consonant-vowels (CVs), common across several Indian languages, had norms established on children. The test, presented through headphones at 40 dB SL, was utilized to confirm that the participants had normal speech identification scores in quiet. Half the participants were tested in the right ear first and half in the left ear, to avoid any ear order effect. Only those with scores greater than 85% in quiet were included in the study. Additionally, the participants were required to have age appropriate language on the Northwestern Syntax Screening Test developed by Lee (1969). The Indian norms of the test, developed by Varma (2001) were used to determine the language age of the children.

Group-II included 100 children in the age range of 6 years to 10 years, who were 'at-risk' for APD. These children had similar inclusion criteria as that of Group-I, except that they had a score of six and more on the SCAP. Table M.2 depicts the age and gender distribution of these children.

Table M.2: *Age and gender distribution of the children who were referred based on SCAP (Group-II)*

Age Range	**No of children**	**Gender**	
		Male	**Female**
6 to 6;11 years	8	5	3
7 to 7;11 years	10	8	2
8 to 8;11 years	35	30	5
9 to 9;11 years	24	16	8
10 to 10;11 years	23	17	6

Equipment

A calibrated dual channel diagnostic audiometer (OB 922 - Version 2) with air conduction (TDH-39) and bone conduction (B-71) transducers was used to carry out pure-tone audiometry, speech audiometry and the APD tests. A calibrated immittance meter (GSI Tympstar) was utilized to ensure normal middle ear function. The APD tests were played through a CD using a Compaq Presario 6000 laptop with Intel Pentium dual core processor.

Test Environment

All the audiological tests were carried out in a sound treated two-room suite with permissible noise limits as specified by ANSI standards (S3.1-1991). The screening checklist, the IQ test and the language screening tests were administered in quiet, distraction-free rooms.

Procedure

All the children enrolled in the study were evaluated on four different APD tests. The tests included 'Speech-in-Noise Test in Indian English' (SPIN-IE; Yathiraj, Vanaja & Muthuselvi, 2009), 'DCV' (Yathiraj, 1999), 'DPT' (Musiek, Baran and Pinherio, 1990)), and 'Revised Auditory Memory and Sequencing Test in Indian-English' (RAMST-IE). SPIN-IE and RAMST-IE were developed as a part of the current study.

Phase I - Development of the test material

Materials were developed for two tests, SPIN-IE and RAMST-IE. Though SPIN in Indian-English and 'Auditory memory and sequencing test in English' (Yathiraj & Mascarenhas, 2003) are available, the need to again develop the tests was felt. Both the earlier developed tests utilized stimuli from an existing speech identification test (Rout, 1996). Additionally, the test developed by Rout is also used to evaluate speech identification in quiet. Thus, the familiarity of the test stimuli could influence the scores obtained by children who are tested with all three tests. Hence, SPIN-IE and RAMST-IE were developed using a new set of test stimuli.

Speech-in-Noise Test in Indian English (SPIN-IE)

The SPIN-IE was constructed using a phonemically balanced word list as the stimuli and an eight-talker babble as the noise. The CD recorded version of the 'Phonemically balanced speech identification test in Indian-English' (Yathiraj & Muthuselvi, 2009) was used as the signal. The stimuli had been recorded by a female with a neutral Indian-English accent. Using a sampling rate of 44,100 Hz and a resolution of 32 bits, the recording had been done using Adobe Audition (version 2) software. The recorded words had been scaled to ensure that the loudness of the words were similar. Yathiraj and Muthuselvi had checked the quality of the recording by carrying out a goodness test on 10 individuals with normal hearing (5 young adults & 5 children aged 6 to 7 years). The test contained 5 equivalent lists, with each list having 25 words. The equivalence of the 5 lists had been established on 60 children aged 6 to 8;11 years. Two of these lists, randomized to produce 2 additional lists, were used for the development of the SPIN-IE.

The eight-talker speech babble (4 males & 4 females) was developed as a part of the current study using fluent English speakers who spoke the language with a neutral Indian accent. It was ensured that all eight talkers spoke with a similar loudness level. Each talker independently read the 'Rainbow passage', at a rate and vocal effort that they typically used. All talkers read the same passage, which was in line with the recommendation of Kalikow, Stevens and Elliott (1977), one of the earliest proponents of SPIN who used speech babble as noise. Eight takers were used to produce the babble as Simpson and Cooke (2005) found that this number of talkers resulted in a higher masking of speech compared to lesser number of talkers. They also found that further increase in talkers did not result in an increase in the deterioration of speech perception. This recording was done using a similar sampling rate and resolution as that used for recording the 'Phonemically Balanced speech identification test in Indian English'. The eight separate recordings that were first normalized after the removal of silence intervals, were superimposed on each other to form the babble. Only the portion of the babble that contained the voice of all eight speakers was retained and used to construct the speech-in-noise test. As the talkers spoke at different rates, the superimposed material at each point of time contained different phonemes.

The speech stimuli and segments of the noise were inserted in two different audio tracks. The speech babble was interrupted to avoid auditory fatigue. The duration of the noise segments was semi-random and varied for from 310 ms to 620 ms. The duration of the interruption was kept constant at 75 ms. It was however ensured that the interruption was not present during the presentation of a stimulus. The interval between stimuli was kept constant at 5 seconds. The average amplitude of each noise segment was matched with that of each word stimulus to ensure that the signal-to-noise ratio was zero. A 1 kHz calibration tone was inserted prior to each of the SPIN-IE lists.

The recorded material was checked on ten individuals with normal hearing (5 young adults & 5 children aged 6 to 7 years), who had not been evaluated earlier on the developed material. The testing was done with and without the presence of noise to check the quality of the recorded material as well as determine the difficulty level of the test. It was found that all the ten individuals were able to repeat all the words in the quiet condition and did not obtain scores lesser than 60% in the presence of noise. As this value was similar to what was reported in the literature (Olsen et al., 1975), no further modification in the material was made.

Revised Auditory Memory and Sequencing Test in Indian-English (RAMST-IE)

The RAMST-IE was constructed using words that were familiar to children aged 6 years and above. The words were taken from a corpus of words that children aged 6 years of age considered highly familiar. The words had been considered highly familiar only if children were able to describe the meaning of the words and report that they used them in day-to-day communication. A set of 650 words that met these requirements was used to develop the test. The words were grouped to form tokens containing 3-word to 8-word sequences. The final test contained varied number of tokens for the different word sequences. While the 3-word and 4-word sequences had two tokens each, the 5-word to 8-word sequences had four tokens each (Appendix I). The total number of words per list was 118.

Two lists were constructed by randomizing the words with both lists containing the same words. However, no word was repeated within each list. The two lists were recorded by a female talker who had a neutral Indian-English accent. The recording was done using Adobe Audition (version 2) software, with a sampling rate of 44,100 Hz with a resolution of 32 bits. The words were scaled to ensure that the intensity of across the words was similar. Within each token, an inter-stimulus interval of 500 ms was maintained between words. This inter-stimulus interval was uniform for all word sequence. This inter-stimulus interval was selected based on the findings of Yathiraj and Vijayalakshmi (2006) who found it to be optimum in the 'Kannada Auditory Memory and Sequencing Test' developed by them. They reported that inter-stimulus intervals of 250 ms and 500 ms yielded similar but better scores than inter-stimulus intervals of 750 ms and 1000 ms. The inter-stimulus interval of 500 ms was selected instead of 250 ms so as to make the task more taxing in order to differentiate between those with and without a memory problem. Between tokens, the inter-stimulus interval varied depending on the length of the word sequence. An inter-stimulus interval of 6 seconds was inserted between the tokens for the 3-, 4- and 5-word sequences. The inter-stimulus interval was increased to 12 seconds for the 6-, 7- and 8-word tokens. The duration of the interval between tokens was based on the average time taken by a group of 5 children aged 6 to 7 years to respond to the stimuli. A goodness test was carried out on a group of 5 young adults and 5 children aged 6 to 7 years to check the quality of the recording. Words that were perceived wrong by more than 20% of these participants, or were reported to be distorted, were rerecorded. A 1 kHz calibration tone was recorded prior to each list.

Phase II: Administration of the APD test battery on typically developing children (Group-I)

The APD test-battery that evaluated monaural auditory separation / closure, auditory integration, temporal patterning and auditory memory, was administered on the 280 children who met the inclusion criteria for Group-I. None of these children had been evaluated earlier, during the development of the material for the study.

SPIN-IE (Yathiraj, Vanaja & Muthuselvi, 2009) was used to evaluate monaural auditory separation / closure; *DCV*, recorded by Yathiraj (1999) was utilized to tested auditory integration; *DPT*, generated and recoded by Gowri (2003) using stimuli similar to the original test developed by Musiek (1994), was employed to evaluated temporal patterning; and *RAMST-IE* (Yathiraj, Vanaja & Muthuselvi, 2009) was used to evaluate higher order cognitive ability associated with auditory processing. All the tests were played through a computer, the output of which was routed to TDH-39 earphones housed in MX-41/AR supra-aural ear cushions, through the diagnostic audiometer. The order in which these tests were administered was randomized to prevent any test order effect. In addition, half the participants were evaluated in the right ear first and half were tested in the left ear first, for the monaural tests (SPIN-IE & DPT), to avoid a ear order effect. The procedure used to administer the test-battery was as described below.

The SPIN-IE was presented at 40 dB SL (ref. PTA). The participants were required to repeat the words heard by them. Each ear was tested independently. The tester marked the responses as correct or wrong on a response sheet. Each correct response was awarded a score of '1' and each incorrect response was scored as '0'. Both raw and percentage scores were noted for each ear for every participant.

The DCV test was played using the CD version of the test at 40 dB SL (ref. PTA). The participants were asked to mark the syllables that were heard through headphones on response sheet which had multiple choices. Single correct and double correct responses were calculated. In the former, the responses of each ear were scored separately and a correct response was given a score of '1' and an incorrect response '0'. While calculating the double correct responses, a score of '1' was awarded only if the responses in both ears were correct and a score of '0' was given if the response was incorrect in either of the ears.

The CD version of the *DPT* was presented at 40 dB SL (ref. PTA). The participants were instructed to verbally report the pattern of the sounds presented in terms of the length. For example, the participant would respond "long, long, short" if the stimulus was LLS. Each ear was tested independently and the responses were noted. The number of correctly identified patterns was noted. Similar to the other tests that were administered a correct response was given a score of '1' and an incorrect response a score of '0'.

The RAMST-IE, developed as a part of the current project, was presented from a computer via an audiometer in two different ways. Half the participants heard the material through two sound-field speakers, each placed at 45^0 azimuth at a distance of one meter from the head of the participant. The other half heard the material binaurally through headphones. The two different modes of presentations were used to check if there was any difference in the presentation mode. The output through both transducers was 40 dB SL (ref. PTA). The participants were asked to listen to each word-sequence and repeat the words heard in the same order as they were presented. The responses were noted by the evaluator on a scoring sheet. Both auditory memory and auditory sequencing were scored separately. While calculating auditory memory, a score of '1' was given for each correctly repeated word. To calculate the auditory sequencing score, an additional score of '1' was given if the words were repeated in the correct order. Both auditory memory and sequencing scores were tabulated in the response sheet (Appendix II).

Phase III: Validation of the APD test battery on children with symptoms of APD (Group-II)

To validate the tests battery, the test battery was administered on a group of children who were categorized as being 'at-risk' for APD based on the scores obtained on the SCAP. Hundred children who got scores of six and more on the SCAP were administered the same tests as Group-I, using the same procedure. The obtained scores were tabulated and scored.

Scoring

The scoring for each test was computed depending upon the scoring procedure given for the particular test. The raw scores were tabulated for further analysis.

Test-retest reliability

Test-retest reliability was assessed for the scores obtained in phase II and phase III. To check for the reliability of the norms obtained in phase II, the test battery was re-administered on 5% of the participants who were randomly selected after an interval of 3 months. However, it was ensured that none of the children on whom the re-test was done, attended any rehabilitation program during this interval.

Analyses

Data obtained from the participants were tabulated and subjected to statistical analysis. The mean and standard deviation was calculated separately for data obtained from males and females in each age group. A mixed design ANOVA with ear as within participant variable and age, gender as between participant variables was carried out separately for SPIN-IE, DCV and DPT. MANOVA was carried out to study the effect of age and gender on auditory memory and sequencing skills. Both MANOVA and Mann-Whitney U test were carried out to compare the results obtained for the two groups as there were unequal number of participants in the two groups. The number of participants in Group II having scores below 1 SD and 2 SD of the mean of Group I was also calculated.

3. Results

The scores obtained on the four diagnostic tests (SPIN-IE, DCV, DPT, & RAMST-IE) were analyzed to determine the effect of age on the auditory processes and auditory memory; Compare the maturational changes across the different auditory processes and auditory memory; Compare the performance of children with symptoms of APD with that of typically developing children to determine the cut-off criteria to classify children as having APD.

3.1 Effect of age on auditory processes & auditory memory

3.1.1 Speech in noise test in Indian-English (SPIN-IE)

The mean and standard deviation of scores obtained for the SPIN-IE are provided in Table R.1. It can be observed from the table that the scores of both the ears increased with increase in age. Similar scores were obtained by boys and girls. A mixed design repeated measure ANOVA was carried out with ear as the within subject variable while age, and gender as the between group variables. Table R.2 shows the results of the analyses. There was no significant effect of ear on the scores, hence for further analysis of the typically developing group, the scores of the left and right ears were combined. Between groups analysis showed a significant effect of age but there was no significant effect of gender. Further, there was no significant interaction among any of the variables.

The results of post hoc analysis for age are shown in Figure R.1. The performance of the 6-year-old children was significantly lower than that of the older age groups. There was no significant difference between the scores of the 7- and 8-year-old children but the mean score of the 7-year-old children was significantly different from that of 9- and 10-year-old children. The performance of 8-year-old children was significantly different from that of 9- and 10-year-old children. There was no significant difference between the scores obtained by 9- and 10-year-old children. Inspection of mean values also indicated a clear increasing trend in scores with increase in age until 9 years of age. The mean scores for the 10-year-old children was slightly lesser than those of the 9-year-old children.

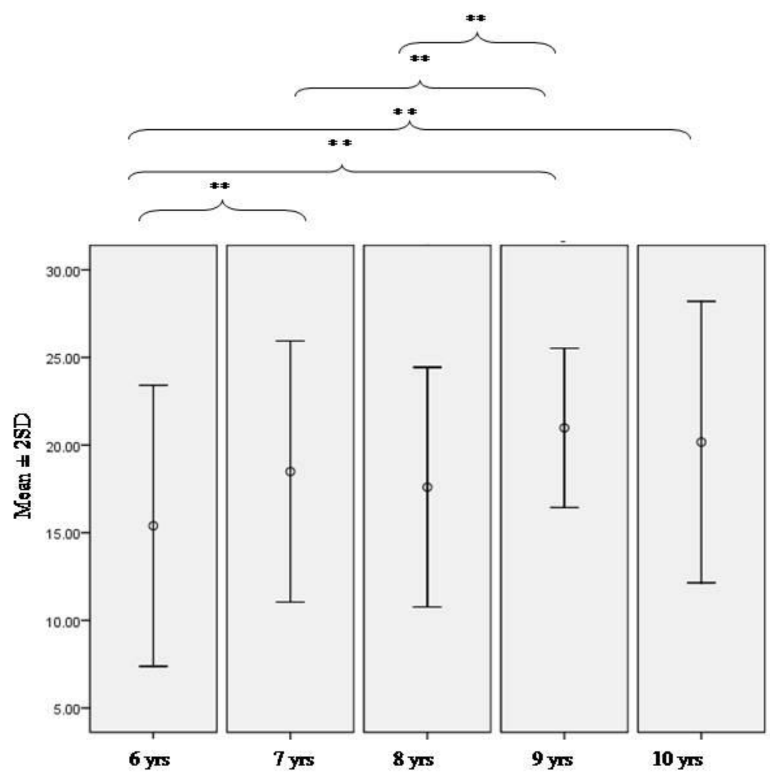
Table R.1: *Mean and SD scores for SPIN-IE*

Age in years	**Statistical tests**	**Right ear**			**Left ear**		
		M	**F**	**T**	**M**	**F**	**T**
6	Mean	16.56	14.41	15.37	16.27	14.72	15.42
	SD	3.91	4.08	4.09	3.86	4.00	3.96
7	Mean	18.54	18.27	18.41	18.90	18.20	18.56
	SD	3.25	3.87	3.53	4.11	3.75	3.92
8	Mean	18.07	17.27	17.66	17.53	17.53	17.53
	SD	3.52	3.01	3.27	3.46	3.76	3.58
9	Mean	21.34	21.06	21.20	21.44	20.12	20.76
	SD	1.87	2.27	2.08	1.84	2.77	2.44
10	Mean	19.50	20. 63	19.81	19.50	20. 34	19.95
	SD	5.05	3.37	4.21	4.81	3.85	4.30

Note. M = Males; F = Females; T = Males + Females
Maximum possible score on SPIN-IE = 25

Table R.2: *Results of ANOVA for SPIN-IE test*

Factor/Group	**Df**	**F value**	**p value**
Ear	1, 268	0.11	> 0.05
Age	4, 268	20.57	< 0.01
Gender	1, 268	1.21	> 0.05
Ear * Age	4, 268	0.75	> 0.05
Ear * Gender	1, 268	0.04	> 0.05
Age * Gender	1, 268	1.21	> 0.05
Ear * Age * Gender	4, 268	1.84	> 0.05



Note: ** = $p < 0.01$; *= $p < 0.05$

Figure R.1. Pair-wise comparison of age effect on SPIN-IE scores (average of left and right scores)

3.1.2. Dichotic CV test (DCV)

The single correct and double correct scores on the DCV test of typically developing children is depicted in Table R.3. In all the age groups, the single correct scores were better than the double correct scores. Additionally, the right ear scores were higher than that of the left ear. With increase in age, there was a steady increase in both the single correct and the double correct scores. Inspection of standard deviation reveals that the variability was highest in the 6-year-old children and least in the 10-year-old children.

Table R.3: Mean *and SD of the single correct and the double correct scores on dichotic CV test across the age groups*

Age	Statistical tests	Right ear score			Left ear score			Double correct score		
		M	F	T	M	F	T	M	F	T
6	Mean	14.35	16.36	17.75	12.58	13.95	13.35	5.7	5.27	5.46
	SD	9.19	6.52	5.48	8.22	5.94	6.96	6.54	5.54	5.92
7	Mean	19.51	17.03	18.31	17.48	17.17	17.33	10.51	9.68	10.11
	SD	4.76	4.46	4.75	4.50	5.72	5.08	5.19	4.66	4.92
8	Mean	21.60	19.63	20.61	19.76	18.80	19.28	11.96	12.60	12.28
	SD	8.29	5.91	7.21	5.27	5.70	5.46	5.85	7.28	6.56
9	Mean	21.44	20.09	20.75	20.75	18.80	19.75	14.34	13.74	14.03
	SD	4.60	6.10	5.42	4.38	6.75	5.77	5.81	6.85	6.32
10	Mean	21.32	21.62	21.48	18.92	19.46	19.21	13.39	12.78	13.06
	SD	4.65	3.88	4.22	5.27	4.12	4.66	5.87	5.16	5.46

Note. M = Males; F = Females; T = Males + Females
Maximum possible single / double correct score = 30

Repeated measure ANOVA (Table R.4) divulged a significant main effect for the scoring procedure (single correct and double correct). Further, pair-wise comparison of the single correct scores for the right ear, left ear and the double correct scores revealed that right and left ear single correct scores were significantly higher than the double correct scores. Also, the right ear scores were significantly larger than that of the left ear. Between subject analyses revealed a significant effect of age but no significant effect of gender. There was no three-way interaction among age, gender and ear scoring procedure. Furthermore, gender did not show any two-way interaction with age or scoring procedure, suggesting a similar trend in both the males and females. However, there was a significant two-way interaction between age and scoring procedure.

Table R. 4: *Results of ANOVA for the dichotic CV test*

Factor/Group	**Df**	**F value**	**p value**
Scoring procedure	1, 269	767.04	< 0.01
Age	4, 269	14.41	< 0.01
Gender	1, 269	0.52	> 0.05
Scoring procedure * Age	4, 269	2.48	< 0.05
Scoring procedure * Gender	1, 269	0.30	> 0.05
Age * Gender	4, 269	0.44	> 0.05
Scoring procedure * Age * Gender	4, 269	2.06	> 0.05

As there was an interaction between the scoring procedure and age, separate repeated measure ANOVA were carried out for each age group to check if there was a significant effect of the scoring procedure in each age group. The F values (Table R.5) revealed a significant ear effect for all five age groups. Pair-wise comparison showed that the single correct scores of both right and left ear were significantly higher than the double correct scores for all the age groups. Despite the scores of the right ear being higher than that of left ear in all the age groups (refer Figure R.2), the difference was statistically significant only in children aged 10 year of age.

Table R.5: *Results of repeated measure ANOVA investigating the ear effect in different age groups for DCV*

Age in years	**df**	**F value**	**p value**
6	2, 72	62.01	< 0.01
7	2,118	89.57	< 0.01
8	2,118	75.10	< 0.01
9	2,118	76.12	< 0.01
10	2,114	142.03	< 0.01

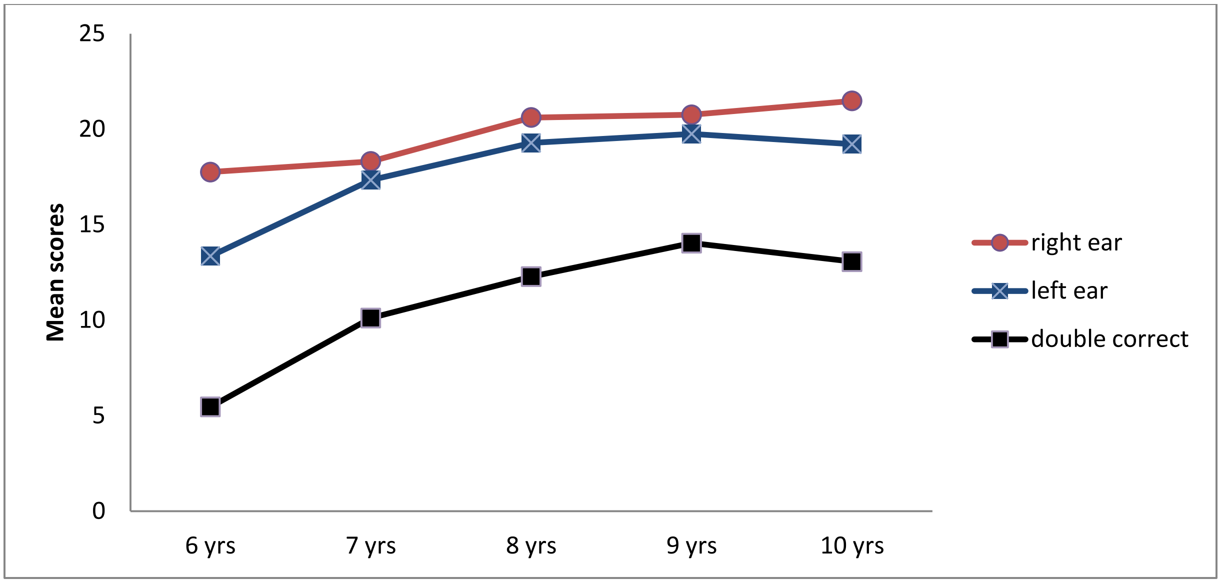
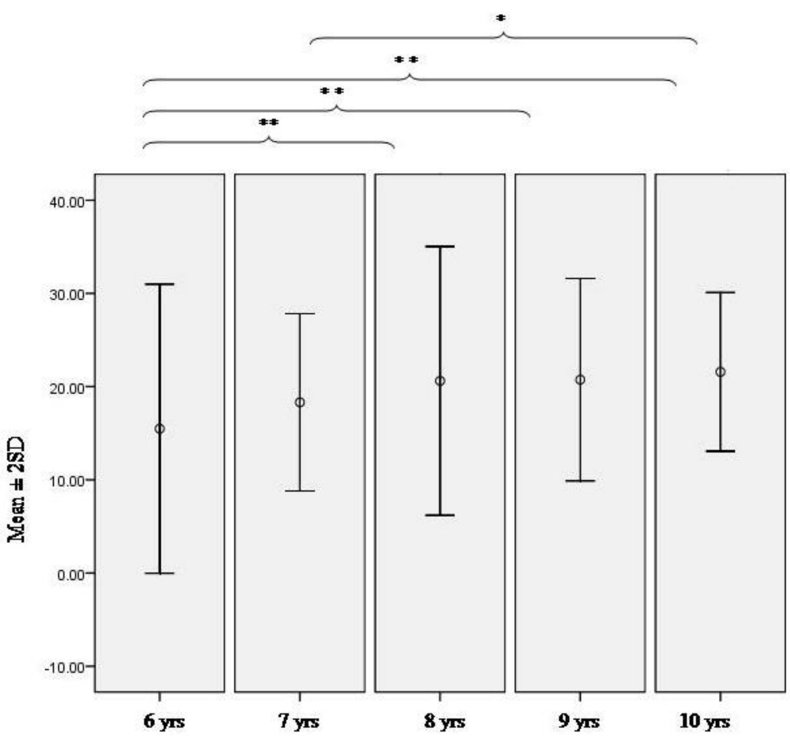


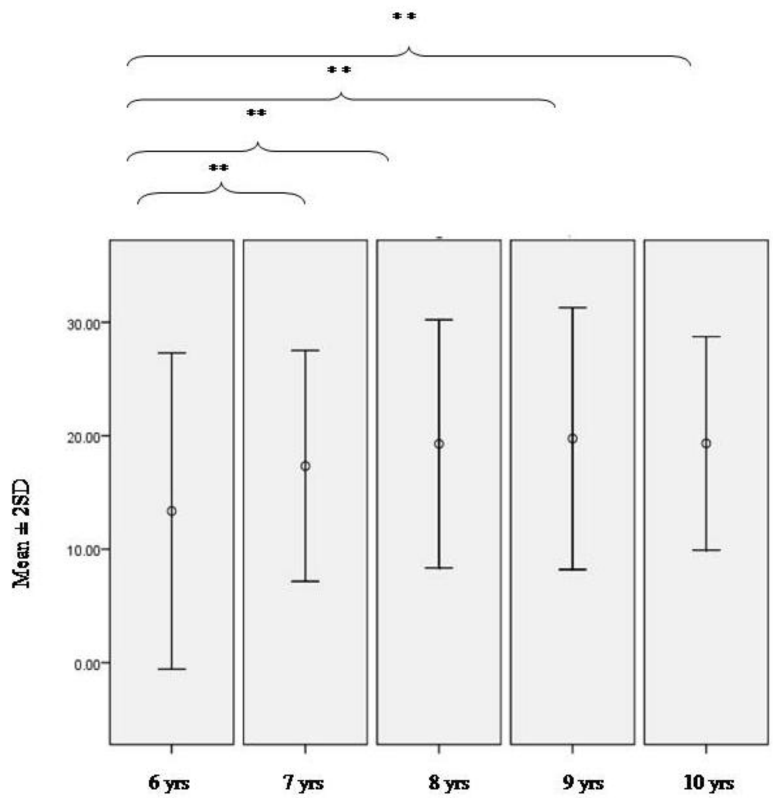
Figure R.2. Mean single correct and double correct scores of dichotic CV test across age groups

MANOVA was carried out to study the effect of age on the right ear, left ear and double correct scores. The results revealed a significant main effect of age for the right ear scores [$F(4, 272) = 8.11$; $p < 0.01$], left ear scores [$F(4, 272) = 10.14$; $p < 0.01$], and for the double correct scores [$F(4, 272) = 15.74$; $p < 0.01$]. The pair-wise comparison for the right ear, left ear and double correct scores are shown in Figures R.3a, R.3b and R.3c respectively. It can be observed that the left ear score of the 6-year-old children was significantly lower than that of the older children. The scores of the left ear of the older children did not show a significant pair-wise difference, though the scores improved with age. A similar pattern was observed for the right ear scores. While the 6- year and 7-year-old children showed a significant difference in performance, no such significant differences was seen for the scores of the 7-year-old and the 8-year-old children, though the older group (8-year-olds) obtained higher scores than the younger group (7-year-olds). The scores of 9- and 10-year-old children were significantly higher than that of 7-year-old children. There was no significant difference between the scores of the 8-years-old children and the older age groups. The double correct scores showed an increasing trend with increase in age. The scores of 6-year-old children were significantly lower than that of the other age groups. The scores of 7-year-old children did not differ significantly from that of 8-year-old children but it was significantly lower than that of 9- and 10-year-old children. Again there was no significant age effect after 8 years of age.



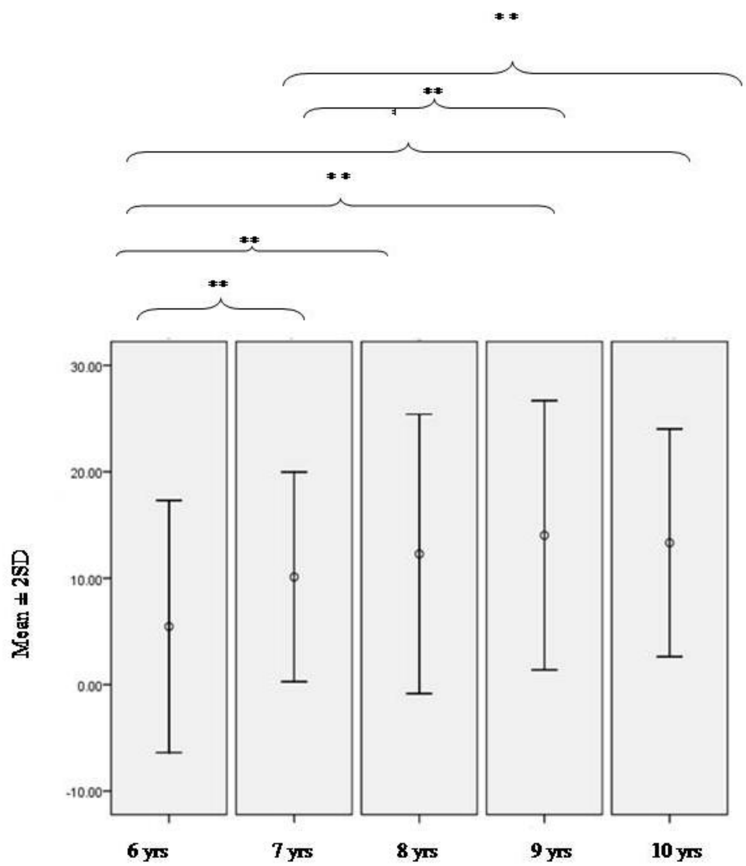
Note: ** = p < 0.01; *= p < 0.05

Figure R.3a. Pair-wise comparison of age effect on DCV-Rt ear



Note: ** = p < 0.01; *= p < 0.05

Figure R.3b. Pair-wise comparison of age effect on DCV-Lt ear



Note: ** = p < 0.01; *= p < 0.05;

Figure R.3c. Pair-wise comparison of age effect on DCV-DC

3.1.3. Duration Pattern Test (DPT)

The descriptive statistics of the DPT is shown in Table R.6. Inspection of the table reveals that the mean scores for 6-year-old children were very low with high variability. As with the other tests the performance of older children was better than that of younger children but the performance of boys and girls were similar. Comparison of ears showed a better performance when the stimuli were presented to the left ear. The results of a mixed design repeated measure ANOVA is given in Table R.7. There was a significant main effect of age as well as ear but there was no significant difference between the scores of the males and females. There was no two-way or three-way interaction.

Figure R.4 shows the results of post hoc analysis. It can be observed that the scores of the 6-year-old children differed significantly from those of all other age groups. The performance of 7-year-old children did not differ significantly from that of the 8-year-old children but it was significantly lower than that of the 9- and 10-year-old children. The scores of the 8-year-old children did not differ significantly from that of the 9-year-old children but differed significantly from that of the 10-year-old children. The scores of the 10-year-old children were higher than that of the 9-year-old children, though there was no significant difference.

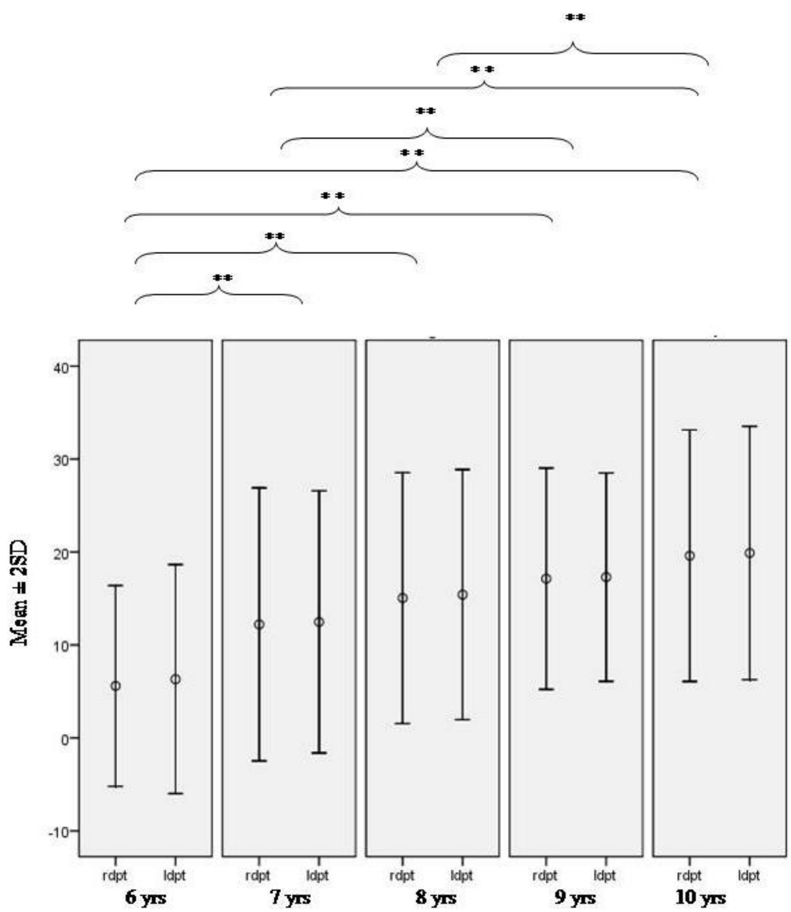
Table R.6: *Mean and SD of scores obtained for Duration Pattern Test*

Age in years	**Statistical Tests**	**Right ear**			**Left ear**		
		M	F	T	M	F	T
6	Mean	6.66	4.73	5.60	7.27	5. 54	6.32
	SD	6.76	3.91	5.40	7.45	4.90	6.15
7	Mean	11.03	13.48	12.21	11.54	13.48	12.48
	SD	5.67	8.71	7.34	5.80	8.16	7.05
8	Mean	15.90	14.20	15.05	15.66	15.16	15.41
	SD	6.19	7.26	6.75	6.48	7.06	6.72
9	Mean	17.06	17.19	17.13	17.24	17.35	17.30
	SD	4.23	7.27	5.95	3.46	7.11	5.60
10	Mean	19.85	19.28	19.55	20.82	18.96	19.83
	SD	6.10	7.47	6.81	6.43	7.28	6.90

Note. M = Males; F = Females; T = Males + Females
Maximum possible duration pattern score = 30

Table R. 7: *Results of ANOVA for the Duration Pattern Test*

Factor/Group	df	F value	p value
Ear	1, 270	5. 22	< 0.05
Age	4, 270	31.37	< 0.01
Gender	1, 270	0.22	> 0.05
Ear * Age	4, 270	0.28	> 0.05
Ear * Gender	1, 270	0.21	> 0.05
Age * Gender	4, 270	0.85	> 0.05
Ear * Age * Gender	4, 270	6.21	> 0.05



Note: ** = p < 0.01; *= p < 0.05

Figure R.4. Pair-wise comparison of age effect on DPT

It can be observed from Figure R.4 and Table R.7 that the variability was very high in 6-year-old children. Hence repeated measure ANOVA was repeated discarding the data of 6-year-old children. Results revealed a significant effect of age ($F(3, 234) = 13.67$; $p > 0.05$) but no effect of ear ($F(1, 234) = 2.32$; $p > 0.05$).

3.1.4. Revised Auditory Memory and Sequencing Test in Indian-English (RAMST-IE)

The mean and standard deviation of the scores obtained on the RAMST-IE is given in Table R.8. Initially independent sample t test was carried out to compare the scores of participants who heard the signal through earphones and those who heard the signal through the loudspeakers. The results showed no significant difference between the two groups for auditory memory scores ($t(275)=1.48$; $p>0.05$) as well as auditory sequencing scores ($t(275)=0.39$; $p>0.05$). Hence, the data of the two groups were combined for further analysis. From the table it can be observed that increase in performance occurred with increase in age for both auditory memory and sequencing skills. The scores of the boys on auditory memory test were higher than that of the girls in all the age groups. MANOVA revealed a significant effect of age on both memory [$F(4, 272) = 11.74$; $p < 0.01$] and sequencing [$F(4, 272) = 6.46$; $p < 0.01$] skills. Gender did not have a significant effect on memory [$F(1, 272) = 1.95$; $p > 0.05$] or sequencing scores [$F(1, 272) = 0.73$; $p > 0.05$]. There was no significant interaction between age and gender ($F(4, 272) = 2.25$; $p > 0.05$ for memory; $F(4, 272) = 0.1.82$; $p > 0.05$ for sequencing).

Table R.8: *Mean and SD of scores obtained for auditory memory and sequencing*

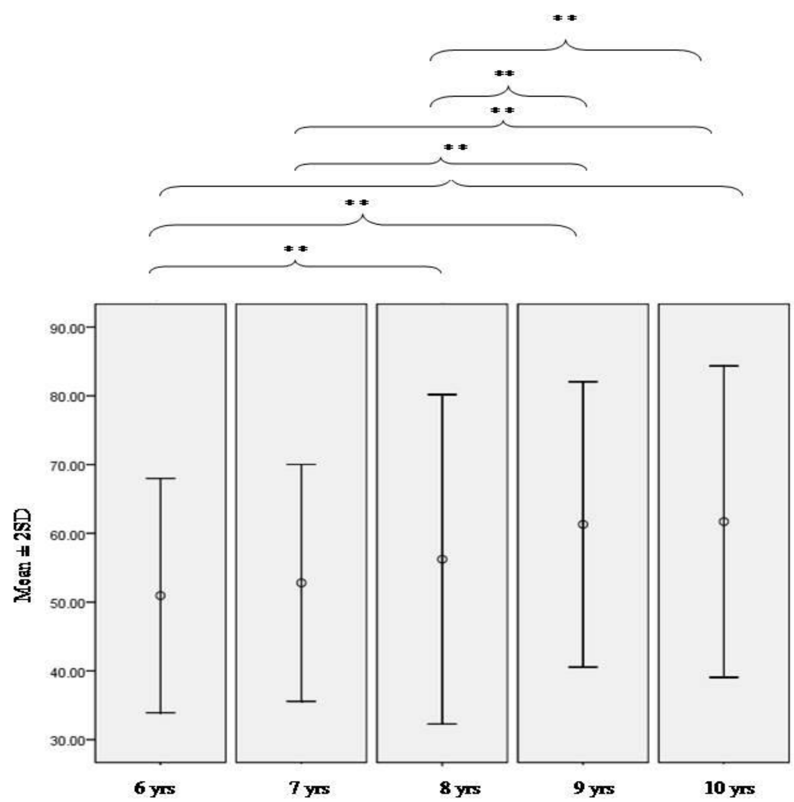
Age in years	**Statistical Tests**	**Memory**			**Sequencing**		
		M	**F**	**T**	**M**	**F**	**T**
6	Mean	50.27	51.82	50.95	33.68	37.83	35.49
	SD	8.97	8.09	8.52	10.97	7.91	9.46
7	Mean	49.41	55.97	52.80	39.23	34.24	36.82
	SD	8.65	7.39	8.61	10.50	9.59	10.27
8	Mean	58.26	54.2	56.23	40.70	36.40	38.55
	SD	11.95	11.85	11.98	12.83	11.03	12.06
9	Mean	60.97	61.66	61.3	44.16	41.62	42.93
	SD	13.32	6.03	10.37	15.52	10.10	13.14
10	Mean	59.77	63.78	61.71	43,63	47.68	45.59
	SD	10.03	12.41	11.32	12.06	16.78	14.54

Note. M = Males; F = Females; T = Males + Females;
Maximum possible memory score = 118;
Maximum possible sequence score = 118.

From Table R.8, it is evident that the mean memory scores were much higher than the mean sequencing scores. This pattern was constant across all the five age groups. Further, with increase in age both auditory memory as well as auditory sequencing scores improved. This increase was seen in the scores obtained by both gender.

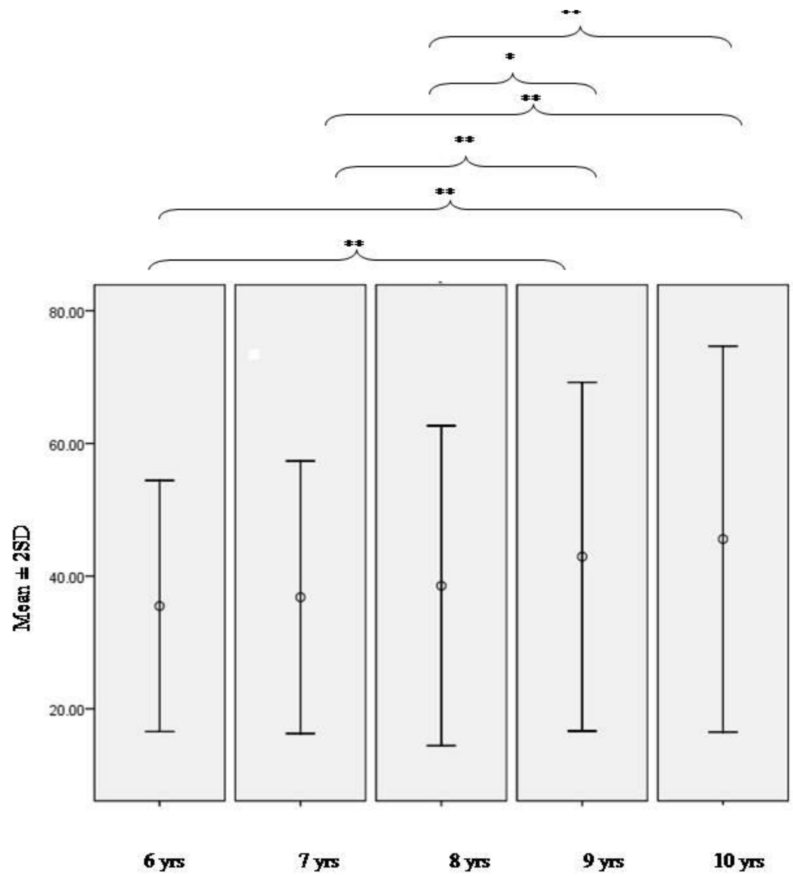
Pair-wise comparisons were carried out to determine how the different age groups differed from each other (Figure R.5a and R.5b). This was done separately for the auditory memory scores and for the auditory sequencing scores. The pair-wise comparison of the memory scores showed that the mean value of the 6-year-old children was significantly lower than that of the 8-, 9- and 10-year-old children. Likewise, the 7-year and 8-year-old children performed significantly poorer than the 9- and 10-year-old children. However, there was no significant difference between the scores of the 9- and 10-year-old children. The mean score of 10-year-old children was significantly higher than that of the 6-, 7- and 8-year-old children.

It was observed that the 6-,7- and 8-year old children performed significantly poorer than 9- and 10- year old children. However, the sequencing scores of the 6-, 7- and 8- year old children did not differ significantly from each other.



Note: ** = p < 0.01; *= p < 0.05

Figure R.5a. Pair-wise comparison of age effect on auditory memory



Note: ** = p < 0.01; *= p < 0.05

Figure R.5b. Pair-wise comparison of age effect on auditory sequencing

The results reveal that depending on the test (SPIN-IE, DCV, DPT & RAMST-IE), the performance of children of different ages differed. This is evident from Table R.9, that provides a summary of significance of difference in the performance of the five age groups for each of the tests.

Table R.9: *Summary of the effect of age of the participants on the four tests (SPIN-IE, DCV, DPT & RAMST-IE)*

Age	**SPIN-IE**				**DCV – Rt**				**DCV – Lt**				**DCV – DC**				**DPT**				**RAMST-IE - Memory**				**RAMST-IE - Sequencing**			
	7	8	9	10	7	8	9	10	7	8	9	10	7	8	9	10	7	8	9	10	7	8	9	10	7	8	9	10
6	**	NS	**	**	NS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	NS	**	**	**	NS	NS	**	**
7		NS	**	NS		NS	NS	*		NS	NS	NS		NS	**	*		NS	**	**		NS	**	**		NS	**	**
8			**	**			NS	NS			NS	NS			NS	NS			NS	**			**	**			*	**
9				NS				NS				NS				NS				NS				NS				NS

Note. ** = $p < 0.01$; * = $p < 0.05$; NS = Not significant

3.2. Comparison of the maturational changes across the different tests

To compare the effect of age on performance of children on the four different tests (SPIN-IE, DCV, DPT, & RAMST-IE), the mean raw scores obtained for each age group was converted to percentage. This was done as the maximum scores of each test varied. Figure R.6 depicts the mean scores of the four tests / sub-tests for children in the five age groups. It can be observed from the figure that auditory sequencing was the most difficult task and understanding speech in noise was the easiest task for children in all the age groups. A non-linear trend, with a steep increase in performance from 6 to 7 years and a shallow increase after 7 years of age, was observed for DPT and DCV-left ear scores. Compared to the other tests, the auditory memory and sequencing abilities showed relatively lesser enhancement in scores with increase in age. The scores of SPIN-IE showed a plateau after 9 years of age whereas the scores of the DPT continued to increase till 10 years of age. The scores of DCV test also showed a plateau after 8 years of age but the percentage scores were lesser than that of SPIN-IE.

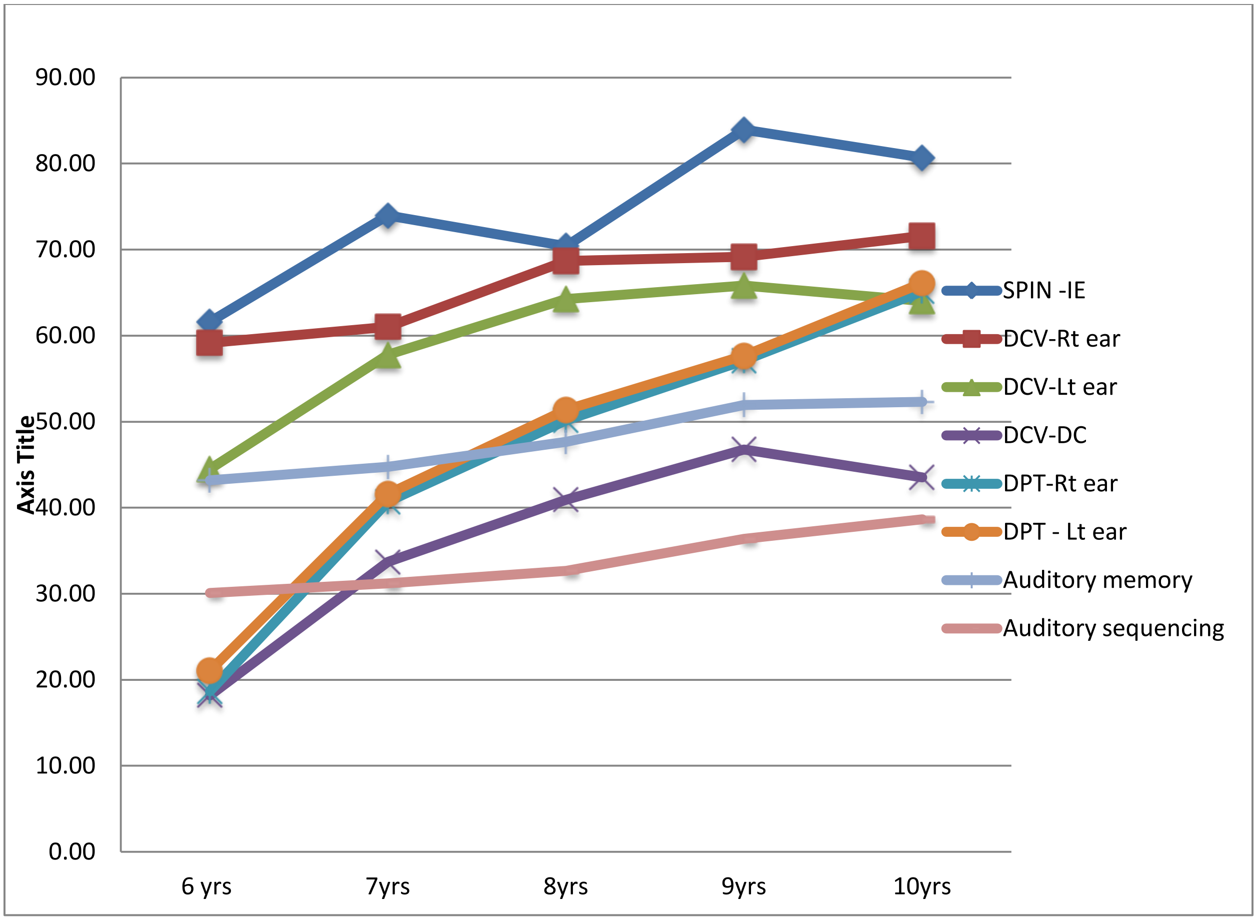


Figure R.6. Mean percentage scores of different tests for children for the five age groups

3.3. Comparison of children with symptoms of APD with those with no symptoms of APD.

The data of the 100 children suspected to have APD based on the results of SCAP were compared with those of typically developing children. The comparison was done with the respective age groups, as significant differences in scores were seen across age groups in the typically developing children. Additionally, the data were also check with a nonparametric test (Mann-Whitney U) as the sample size in the two groups was unequal. Table R.10 a, b, c, d, e shows the mean, standard deviation as well as results of the MANOVA and Mann-Whitney U tests for the different age groups. It can be observed from the tables that the mean scores for children with suspected APD is lesser than that of their respective age groups for all the tests. For the 6-year-old children a significant difference between the two groups was observed for the SPIN-IE test, double correct scores of the DCV test, and both auditory memory and sequencing subtests of RAMST-IE test. For the remaining age groups, a significant difference was found between the two participant groups for all the tests except for auditory memory in the 7-year-olds, SPIN - left ear in the 8-year-olds and dichotic CV - left ear in the 10-year-old-children.

Table R.10 a. Comparison of 6-year-old children suspected to have APD with age matched typically developing children

		Typically developing children (N:40)		**Children with suspected APD (N:8)**		**Mann Whiteny U test**	**MANOVA**
		Mean	**SD**	**Mean**	**SD**	**Z**	**F(1,27)**
SPIN-IE	Right	15.40	4.01	8.25	5.0	-3.12**	63.14**
	Left			10.63	5.53	-2.36**	29.64**
DCV	Right	15.49	7.75	11.00	6.28	-1.66*	1.10
	Left	13.36	6.96	10.63	6.80	-1.12	0.97
	Double correct	5.49	5.92	1.25	1.83	-2.00*	9.70**
DPT	Right	5.60	5.4	5.60	2.56	-.29	0.03
	Left	6.33	6.16	5.13	3.09	-.25	-.05
Auditory Memory		50.95	8,52	39.75	18.77	-1.73	7.16*
Auditory Sequence		35.49	9.46	1.25	3.54	-4.43**	100.35**

Note: ** = p < 0.01; *= p < 0.05

Table R.10 b. Comparison of 7-year-old children suspected to have APD with age matched typically developing children

		Typically developing children (N:60)		Children with suspected APD (N:10)		Mann Whiteny U test	MANOVA
		Mean	**SD**	**Mean**	**F(1,27)**	***Z***	**F(1,65)**
SPIN-IE	Right	18.49	3.72	12.60	2.99	-4.05**	33.33**
	Left			13.1	2.28	-3.79**	25.45**
DCV	Right	18.32	4.75	14.9	3.78	-2.17**	5.08*
	Left	17.33	5.09	12.7	4.45	-2.52**	8.49**
	Double correct	10.12	4.92	5.2	4.29	-2.75**	11.00**
DPT	Right	12.22	7.34	2.70	5.45	-3.95**	16.26**
	Left	12.48	7.05	2.3	4.29	-4.32**	20.13**
Auditory Memory		52.80	8.61	48.00	5.31	-1.71	2.89
Auditory Sequence		36.82	10.27	17.90	8.78	-4.11*	27.94*

Note: ** = $p < 0.01$; *= $p < 0.05$

Table R.10 c. Comparison of 8-year-old children suspected to have APD with age matched typically developing children

		Typically developing children		Children with suspected APD		Mann Whiteny U test	MANOVA
		Mean	**SD**	**Mean**	**SD**	**Z**	**F(1,93)**
SPIN-IE	Right	17.60	3.42	14.28	3.67	-4.33**	21.59**
	Left			16.08	4.53	-1.62	2.96
DPT	Right	15.05	6.75	8.46	7.31	-4.07**	19.84**
	Left	15.42	6.73	9.14	7.76	-3.74**	17.16**
DCV	Right	20.62	5	14.17	6.02	-4.09**	19.86**
	Left	19.28	5.47	15.37	5.92	-3.02**	10.64**
	Double correct	12.28	6.56	6.06	4.75	-4.43**	24.09**
Auditory Memory		56.23	11.98	47.17	12.61	-3.30**	12.17**
Auditory Sequence		38.55	12.06	23.46	11.50	-5.16**	35.81

Note: ** = $p < 0.01$; *= $p < 0.05$

Table R.10 d. Comparison of 9-year-old children suspected to have APD with age matched typically developing children

		Typically developing children		**Children with suspected APD**		**Mann Whiteny U test**	**MANOVA**
		Mean	**SD**	**Mean**	**SD**	**Z**	**F(1,78)**
SPIN-IE	Right	20.98	2.27	15.00	5.73	-4.91**	49.52**
	Left			15.00	5.39	-4.99**	42.71**
DPT	Right	17.13	5.95	12.13	8.50	-2.74**	11.39**
	Left	17.30	5.6	12.50	7.89	-2.75**	12.19**
DCV	Right	20.75	4.5	15.79	9.01	-2.29*	12.01**
	Left	19.75	5.77	15.70	7.74	-2.20*	7.62**
	Double correct	14.03	5.6	8.71	7.22	-2.77**	13.71**
Auditory Memory		61.30	10.37	54.45	12.69	-2.97**	6.55**
Auditory Sequence		42.93	13.14	27.50	16.59	-4.19**	20.27*

Note: ** = p < 0.01; *= p < 0.05

Table R.10 e. Comparison of 10-year-old children suspected to have APD with age matched typically developing children

		Typically developing children		**Children with suspected APD**		**Mann Whiteny U test**	**MANOVA**
		Mean	**SD**	**Mean**	**SD**	**Z**	**F(1,76)**
SPIN-IE	Right	20.17	4.01	17.43	4.78	-2.55**	7.26**
	Left			17.35	4.81	-2.79**	8.86**
DPT	Right	19.55	6.82	12.61	8.13	-3.33**	15.99**
	Left	19.83	6.9	12.17	8.99	-3.52**	17.89**
DCV	Right	21.48	3.5	18.13	5.46	-2.67**	9.85**
	Left	19.22	4.67	17.65	5.51	-1.05	1.45
	Double correct	13.07	4.3	9.39	7.05	-2.23*	7.34**
Auditory Memory		61.79	11.32	51.87	8.2	-3.75**	14.33**
Auditory Sequence		49.59	14.34	35.09	13.62	-2.61**	8.99**

Note: ** = p < 0.01; *= p < 0.05;

3.4. Cut-off criteria to classify children as having APD

To determine the hierarchy of tests that are failed by children with symptoms of APD, the number of children who failed each of the tests were determined. Table R.11 shows the lower cut-off scores that are 1 and 2 SD lower than the mean scores in the respective age groups. Using the cut-off scores given in Table R.11, the number and percentage of children who failed different tests was determined. Table R.12 shows the number and percentage of children who failed the different tests.

Table R 11: Lower cut-off scores for identifying APD based on the normative data obtained on typically developing children at -1 SD and -2 SD of the mean.

Age groups	**6**		**7**		**8**		**9**		**10**	
	-1 SD	-2 SD	-1 SD	-2 SD	-1 SD	-2 SD	-1 SD	-2 SD	-1 SD	-2 SD
SPIN-IE	11.40	.7.40	14.77	11.05	14.19	10.7	18.71	16.44	16.16	12.15
DPT Right	0.2	0	4.88	0	8.3	1.55	11.18	5.23	12.73	5.91
DPT Left	0.17	0	5.43	0	8.69	1.96	11.7	6.1	12.93	6.03
DCV Right	12.27	6.79	13.57	8.82	15.62	10.62	16.25	11.75	17.98	14.48
DCV Left	6.39	0	12.24	7.15	13.81	8.34	13.98	8.21	14.55	9.88
DCV Double correct	0	0	5.2	0.28	5.72	0	8.43	2.83	8.77	4.47
Memory	42.45	33.93	44.19	35.58	44.25	32.27	50.93	39.96	50.39	39.07
Sequence	26.03	16.57	26.55	16.28	26.49	14.43	29.79	16.65	31.05	16.51

Table R. 12: Number of children (with percentage in brackets) in Group II who scored less than -1 SD and -2 SD of the mean of their respective age groups

	-1 SD	**-2 SD**	**-1 SD**	**-2 SD**	**-1 SD**	**-2 SD**	**-1 SD**	**-2 SD**	**-1 SD**	**-2 SD**	**-1 SD**	**-2 SD**
Age group	**6**		**7**		**8**		**9**		**10**		**6 to 10**	
No. of children	8		10		35		24		23		100	
SPIN Rt	7 (87.5%)	7 (87.5%)	8 (80%)	6 (60%)	21 (60%)	15 (42.9%)	16 (66.7%)	12 (50%)	6 (26.1	4 (17.4%)	58 (58%)	44 (44%)
SPIN Lt	6 (75%)	5 (62.4%)	7 (70%)	5 (50%)	12 (34.3%)	10 (28.6%)	20 (83.3%)	12 (50%)	7 30.4%)	5 (21.7%)	52 (52%)	37 (37%)
DPT Rt	0 (0%)	0 (0%)	8 (80%)	0 (0%)	20 (57.1%)	8 (22,1%)	11 (45.8%)	6 (25%)	13 (56.5%)	5 (21.7%)	52 (52%)	19 (19%)
DPT Lt	0 (0%)	0 (0%)	7 (70%)	0 (0%)	17 (48.6%)	8 (22.1%)	12 (50 %)	6 (25%)	13 (56.5%)	4 (17.4%)	49 (49%)	18 (18%)
DCV Rt	2 (25%)	1 (12.5%)	4 (40%)	0 (0%)	17 (48.6%)	8 (22.9%)	9 (37.5%)	6 (25%)	10 (43.5%)	4 (17.4%)	42 (42%)	19 (19%)
DCV Lt	1 (12.5%)	1 (12.5%)	4 (40%)	0 (0%)	12 (34.3%)	2 (5.7%)	9 (37.5%)	3 (12.5%)	6 (26.1%)	3 (13%)	32 (32%)	9 (9%)
DCV double correct	5 (62.5%)	5 (62.5%)	6 (60%)	0 (0%)	20 (57.1%)	0 (0%)	10 (41.7%)	9 (37.5%)	11 (47.8%)	9 (39.1%)	52 (52%)	23 (23%)
Memory	4 (50%)	3 (37.5%)	1 (10%)	0 (0%)	13 (37%)	5 (15%)	10 (42%)	2 (8%)	8 (35%)	2 (9%)	36 (36%	12 (12%)
Sequence	7 (87.5%	7 (87.5%)	3 (30%)	2 (20%)	16 (46%)	2 (6%)	11 (46%)	2 (8%)	8 (35%)	2 (9%)	45 (45%)	15 (15%)

Among the children with suspected APD, it was found that with the -1 SD cut-off criteria, the number of children who passed all the tests (8 children) and the number who failed one test (16 children),) was less compared to the number who failed in more than one test (76 children). However, with the -2 SD cut-off criteria, the number of those who passed all the tests increased to 28 as well as those who failed one test increased to 38 and the number who failed more than one test reduced to 34. While deciding the number tests that were failed, the auditory 'memory' scores and the auditory 'sequencing' scores were considered separately. This was done, as there was a marked difference in these two scores in the typically developing children in all the age groups.

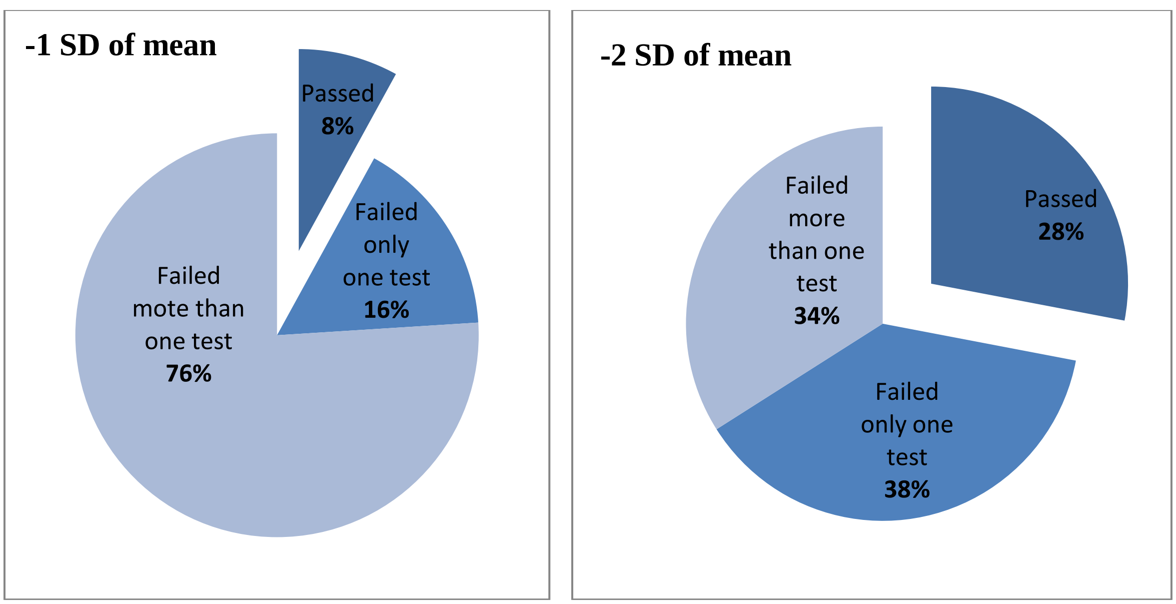


Figure R.7: Number of children among the 100 with suspected APD who passed or failed tests with two different cut-off criteria (-1 SD of the mean & -2 SD of the mean)

Test retest reliability was checked on 5% of the total population that included the typically developing and children with symptoms of APD. Pearson's correlation coefficient was found to vary from 0.65 to 0.8 across the test. These values were found to significant at the

0.001 level of significance.

The results of the present study are discussed with those reported in the literature in the next section. The discussion is done for the results obtained for the typically developing children as well for the children with symptoms of APD.

4. Discussion

The findings of the study on *maturational changes across different auditory processes / auditory memory* indicated changes in performance with increase in age. The study revealed that children as young as 6 years were able to carry out the auditory tests for APD. This suggests that children aged 6 years and above can be assessed using standard tests for APD. In general, the 6 year old children performed significantly poorer than the older age groups, in most of the tests. An exception to this was their performance in the right ear on the DCV test and in the RAMST-IE. Additionally, it was observed that the 7 year old children did not differ significantly from the older children, especially from the adjacent older group. This indicates that there was a plateau in performance between the ages of 7 to 8 years, and further improvement in performance as the children grew older. This growth in performance varied from test to test, as can be seen in Table R. 9 and Figure R.5. From the findings of the current study, it can be construed that maturation of auditory processing is non-linear. The study also reveals that maturational changes continue even in the older age groups that were evaluated. The general increase in performance with increase in age observed in all the tests highlights the need to obtain age appropriate normative data.

The results obtained in the study are similar to those reported in the earlier literature. The effect of age has been demonstrated for speech in noise test (Lewis et al, 2010; Fallon, 2001;

Whitelaw & Yuskow, 2005; Elliot, 1979), DCV test (Bellis, 1996, 2003; Krishna & Yathiraj, 2001; Keith, 1984; Willeford & Burleigh, 1994), DPT (Bellis, 1996, 2003; Musiek et al., 1980; Musiek, Kibbe & Baran, 1984) as well as auditory memory and sequencing test (Yathiraj & Vijayalakshmi, 2006; Gardner, 1996). As the age ranges studied and the stimuli used vary from study to study, comparison across studies is difficult. However, age related changes in performance, attributed to the morphological changes that occur in the central auditory pathway (Romand, 1983), is reported to be complete by 10 to 12 years of age (Bellis, 1996, 2003). The findings of the present study indicate that most of the auditory processes that were studied, continue to develop in children aged 10 years and 11 months of age.

Most researchers have provided scores on APD tests for children older than 7 years. Information on APD test scores for children as young as 6 years of age is sparse. ASHA (2005) do not advocate testing children having a mental age below 7 years on APD tests as such children are likely to find the task difficult, thereby affecting the test results. Similarly, as per the AAA (2010) guidelines for the 'Diagnosis, Treatment and Management of Children and Adults with Central Auditory', APD tests can be carried out on those with a "minimum developmental age of seven or eight years, or a level of cognitive functioning that is consistent with this age range" (pp 14). However, from the findings of the present study, it is evident that it is possible to carry out certain APD tests (SPIN-IE, DCV and RAMST-IE). Despite the 6 year old children obtaining significantly poorer scores than older children on most of these tests, the variability in performance was similar or less than that obtained by the older children for these three tests. As the variability in performance in this age group is not very large, the normative data obtained on them can be utilized usefully to make early diagnosis of the condition.

However, Stollman, Neijenhuis et al. (2004), in a study on Dutch children, have demonstrated that tests for APD can be done on children as young as 4 years of age.

While the 6-year-old children were able to carry out most of the tests, the results of the present study indicate that it is difficult to administer DPT in this age group. It was observed that only two children obtained a score of more than 21, 6 children scored between 10 and 20 and the remaining children obtained a score of 0 on this test. The response mode used in the present study required linguistic labelling of the pattern that was heard. Probably it was difficult as it tapped temporal processing as well as inter-hemispheric functioning. Thus, the DPT requiring verbal responses is not a good test to assess temporal processing in 6-year-old children. Studies need to be carried out to investigate if the performance is better for humming responses. The mean scores reach 50% only by 9 years of age. These results are similar to those reported by Bellis (2003) who opined that the test is too difficult for children younger than 9 years.

The *gender of the participants* was found to not affect the performance on the tests. Besides there being no significant difference between the genders, no interaction was seen between age and gender for all the four tests. This indicates that the maturation of the auditory nervous system is similar in boys and girls in the age range of 6 to 10 years. Thus, it can be construed that there is no need to have separate norms for males and females. Earlier studies have also reported no gender differences in the performance on tests of APD speech in noise test (Stollman, Neijenhuis et al., 2004), DCV test (Berlin, 1973), DPT (Turkyilmaz, Yilmaz, Yagcioglu, Yarali, & Celik, 2012) as well as auditory memory and sequencing test (Devi, Sujita, & Yathiraj, 2006; Gathercole, Pickering, Ambridge, & Wearing, 2004; Yathiraj, & Vijayalakshmi, 2006).

The *performance across the two ears* was found to be similar for SPIN-IE and DPT. This supports the results of earlier investigations (Gauri, 2003; Musiek, Baran and Pinherio, 1990) where similar performance is seen for the monoaural auditory separation / closure task as well as temporal processing. Unlike what was observed with SPIN-IE and DPT, a significant ear effect was observed for the DCV single correct scores for the right and left ears. The ear difference observed for the single correct DCV tests scores reflects the typical right ear advantage that is reported in several studies in literature in children (Krishna, 2001) and in adults (Prachi, 2002). The right ear advantage in the current study was more marked in the youngest age group, and the oldest age group. However, an analysis of the ear effect in each group separately revealed a significant difference only in 10-year-old children. No significant difference probably occurred in the youngest age group due to the high variability in their scores that was reflected in a higher SD compared to the other age groups. The right ear advantage reduced in the girls aged 7 to 9 years and boys aged 8 to 9 years. This suggests that in the older children the asymmetry in the two hemispheres reduces, but continues to be maintained. An increased right ear advantage reappeared in the oldest age group (10 years). It is possible that in the younger age group the asymmetry is a reflection of a lower auditory centre and the asymmetry reduces as the higher centres start to take over. The asymmetry probably reappears when the higher centres take over the function. The ear effect of RAMST-IE was not analysed since the stimuli were presented binaurally through earphones.

There is a dearth of studies *comparing the effect of maturation on speech-in-noise, dichotic CV, duration pattern and auditory memory and sequencing* in the same group of children. In the present study, the comparison of performance of the children across the tests indicated that the auditory closure and monaural separation ability as assessed by SPIN-IE is developed early in childhood and stabilizes by 9 years of age. However, based on the performance on the DPT, it is difficult to state whether temporal ordering is not developed till 8 years of age or whether children have difficulty in linguistic labelling due to immature corpus callosum. The results of DCV test suggest that auditory capacity to integrate stimuli heard in two the ears is very low in 6 year old children and reaches a plateau by 9 years of age. However, these scores were lower than that reported for adults (Prachi, 2001). The single correct scores were higher than the double correct responses, indicating that children were able to identify stimuli presented to one ear if they ignored the stimuli heard in the other ear.

The performance of the children on the RAMST-IE varied depending on the scoring procedure that was used that assessed different memory skills. In general it was observed that children in all age groups performed better when the 'memory' scores were calculated compared to when 'sequencing' scores were calculated. This can be attributed to the difficulty in the tasks. In the latter scoring procedure, the children were required to not only remember the words but also the correct sequence, while in the former scoring procedure they were not required to remember the order of the stimuli. Although there were differences in the scores for 'memory' and 'sequencing', both types of scores increased with increase in age. For the memory scores, the younger three age groups did not differ from those in the adjacent age groups (i.e. 6 year olds did not differ from the 7 year olds and the 7 year olds did not differ from the 8 year olds). Likewise, the oldest two age groups did not differ from each other. An almost similar trend was seen for the sequencing scores also. This indicates that the maturation of auditory memory and sequencing is not uniform across different age groups. In the younger (6 to 8 year olds) and older age groups (9 to 10 year olds), the growth in auditory memory and sequencing is more gradual. However, it is more rapid between 8 to 9 years of age (Table R 9).

The findings of auditory memory and sequencing are similar to what has been reported in the literature. Gathercole et al. (2004) also observed a significant age effect for auditory memory in children aged 4 years to 15 years using a word task, digit task and non-word task. Similarly, Devi et al. (2006) reported of an increase in auditory memory with increase in age on an auditory memory and sequencing test in English in children aged 6 to 12 years. The results indicated that auditory memory scores increased with advance in age up to ten years, after which a plateau was obtained. In a similar manner, Yathiraj and Vijayalakshmi (2006) also found a significant age effect on a Kannada auditory memory and sequencing test in children aged 5 to 11 years. The significant difference was observed between each of the six 1-year-interval age groups.

From the findings of the present study, it can be inferred that all four tests that were evaluated (SPIN-IE, DCV, DPT & RAMST-IE) had maturational effects. However, the rate at which each of the tests developed varied. While certain tests had steep increase in scores with increase in age (DCV - double correct responses, DCV - right ear responses & DPT) other had gradual increase with age (RAMST-IE & SPIN-IE). Thus, it can be construed that different auditory processes have different rates of development, which is a reflection of the development of the different areas controlling the processes.

The *results of the 100 children who were suspected to have APD* indicated that overall the tests that they failed most frequently were the SPIN-IE, DPT and DCV-DC. This was seen when the data of all five age groups were combined. However, on observation of the results of each age group, the tests that were failed most frequently were SPIN-IE and DCV-DC. This occurred since none of the children failed the DPT test in the youngest age group. This probably was on account of the typically developing children in this age group having highly variable results, thus making the DPT norms of this age group unreliable (Table R.6). This is evident as the mean scores of the 6 year olds were lower than their SD. As DPT is not a reliable test for typically developing children aged 6 years of age, it was not able to detect temporal problems in those with suspected APD, in this age group. Thus, the tests that were failed most often across the five age groups were SPIN-IE and DCV-DC.

The results of the present study suggest that SPIN-IE and DCV-DC tests can identify children with APD in all the age groups. These results are similar to those reported earlier in literature (Schow & Chermak, 1999; Keith 1995). Further, among the behavioural indicators of APD, understanding speech in the presence of noise is one of the most frequently reported problems of children with APD (Lagace, Jutras, & Gagne, 2010). Listening in the presence of others' speech has also been found to be a difficult task.

From the findings of the present study, the DPT is not recommended as a test of choice while assessing 6-year-old children. It has been reported in literature that results of gap detection test are reliable in children as young as 5 years of age (Keith, 2000). Probably the DPT is more taxing as it involves linguistic labelling of the temporally processed signals while gap detection test assesses only temporal processing.

The results of the current study suggest that SPIN-IE, DCV as well as RAMST-IE help identify APD even in 6-year-old children. However, Bellis (2003), ASHA (2005) and AAA (2010) recommended that the tests of APD be administered only after children are 7 years of age. Similarly, the guidelines for screening, identification and management of APD by Colorado Education Department (2008) states that screening is generally not appropriate until a child is of 5 or 6 years of age and assessment is generally not appropriate for children younger than 7 years of age. In the present study when the cut-off score was set at 2 SD below the mean value of a particular test, 6 children failed on the SPIN-IE and auditory sequencing test, 4 children failed on SPIN-IE and DCV test and 3 children failed on SPIN-IE, DCV test and auditory sequencing test.

From the results of the number of children who passed and failed the APD tests (Figure R.7), with a more stringent criteria (-1 SD below the mean for each test), the number of children who passed was just 8 (8%) and the number who failed one or two tests was as high as 92 (92%). However, with the less stringent criteria (-2 SD below the mean for each test) the number who passed increased to 28 (28%) and the number who failed dropped to 72 (72%). As a larger number of children could be identified with the stricter cut-off criteria, it is recommended that this be used while diagnosing a child as have APD. This is recommended as these children had at least six symptoms of APD (the criteria used in SCAP to refer a child for dialogistic testing). However, the number of children who failed only one test was lesser when the -1 SD criteria was used when compared to when the -2 SD criteria was used. Hence, the -2 SD criteria is recommended when children fail only one test and the -1 SD criteria is recommended when children fail more than one test. These findings are in consensus with that of Chermak and Musiek (1997), though the actual value of the cut-off criteria differed. They too recommended the use of the criteria of 3 SD below the mean if the individual failed only one test, and at least 2 SD below the mean if the individual failed on two or more tests in the APD battery.

From the findings of the study, it can be seen that using the battery consisting of SPIN-IE, DCV, DPT and RAMST-IE, the majority of children with symptoms of APD can be detected. This battery of test would provide information regarding the particular auditory process or higher cognitive function that is deviant in those with symptoms of APD. Such information would be highly beneficial in making further recommendations for management for individuals detected to have APD.

5. Conclusion

The present study was carried out with the aim to establish normative data on a battery of four tests (SPIN-IE, DCV, DPT and RAMST-IE) in 280 typically developing children aged 6 to 10 years. The tests tapped auditory closure / monaural separation, binaural auditory integration abilities, temporal processing abilities as well as auditory memory and sequencing abilities. The study also determined the maturational changes for each of the auditory skill that were evaluated and compared these age related changes across the tests. Further, based on the performance of 100 children with symptoms of APD, cut-off scores to diagnose APD were determined for each test.

Analyses of the data obtained from the typically developing children showed that the older children performed better than the younger children, stressing the need to develop age appropriate norms. Although age had an effect on the results of all the tests, the rate of improvement in performance varied across the tests. The results indicated that assessment of APD can be carried out on children as young as 6 years. The 6-year-old children could be tested using all the tests except DPT. Analyses of data obtained from children with suspected APD revealed that SPIN-IE and DCV-DC help in identifying APD in all the age groups. While children aged 7 years and above could perform the DPT, those aged 6 years found the task too difficult and hence it is recommended that it should not be included in the test battery for children below 7 years of age. Further, there was no significant difference between the performance of boys and girls. An ear effect was observed only for the DCV test.

From the findings of the children having symptoms of APD, it is recommended that a criterion of 2 SD below mean of typically developing children should be for diagnosing APD for children who performed poorly on only one test. However, for children performing poorly in more than one test on the APD test battery, it is recommended that a cut-off criterion of 1 SD below the mean of typically developing children should be used. The recommended cut-off criteria were found to be effective in diagnosing the majority of children with symptoms of APD, as specified in the screening checklist for APD (SCAP). With either of the cut-off criteria, it was found that the test that was failed most often was SPIN-IE, followed by DCV-DC, DPT and RAMST-IE. With the elimination of any one of the tests from the battery, the number of children identified to have the condition reduced. Hence, it is recommended that all four tests be used to identify APD in children as they tap different auditory processes.

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Appendix I

'Revised Auditory Memory and Sequencing Test' (RAMST-IE) – List-1

Sl. No	Token	Word Sequence	Stimuli							
1	1	3-word	Dog	Car	Rose					
2	2	3-word	Tree	Goat	Big					
3	1	4-word	Home	Chips	Rope	Stick				
4	2	4-word	Blue	Nest	Rock	Step				
5	1	5-word	Joy	Fast	Shout	Pull	Cake			
6	2	5-word	Late	Hot	Milk	Taste	Sit			
7	3	5-word	Grass	Train	Eat	Hair	Bank			
8	4	5-word	Fan	Bed	Frog	Stool	Ball			
9	1	6-word	Hide	Rich	Skirt	Run	Door	Mouth		
10	2	6-word	Girl	Bat	Clap	White	Clock	Sweet		
11	3	6-word	Stop	Ring	Bulb	Fish	Book	Shop		
12	4	6-word	Mouse	Bike	Cow	Son	Grapes	Three		
13	1	7-word	Wright	Bus	Tap	Head	Sky	Flag	Soup	
14	2	7-word	Hut	Prize	Ten	Fruit	Jar	Doll	Roof	
15	3	7-word	Walk	Boy	Zoo	Soap	Red	Test	Sheep	
16	4	7-word	Bell	Chair	Tall	Fox	Bag	Hen	Key	
17	1	8-word	Class	Rat	Sing	Plate	Cloud	Duck	Bring	Pray
18	2	8-word	Van	Dish	Egg	Tea	Jug	Stand	Gum	Shop
19	3	8-word	Desk	Eye	Blank	Knife	Toy	Sleep	Neck	Crow
20	4	8-word	South	Gold	Star	Cream	Cap	Bird	Kite	Jump

'Revised Auditory Memory and Sequencing Test' (RAMST-IE) – List-II

Sl. No	Token	Word Sequence	Stimuli							
1	1	3-word	Cap	Kite	Eye					
2	2	3-word	Tea	Jug	Shop					
3	1	4-word	Cream	Plate	Boy	Skirt				
4	2	4-word	Fish	Bike	Grapes	Rock				
5	1	5-word	Desk	Bank	Class	Hut	Fast			
6	2	5-word	Bed	Rich	Train	Step	Cow			
7	3	5-word	Cloud	Dish	Bag	Key	Shout			
8	4	5-word	Walk	Zoo	Stand	Home	Star			
9	1	6-word	Black	South	Door	Chair	Fox	Soap		
10	2	6-word	Late	Juice	Frog	Sleep	Toy	Ring		
11	3	6-word	Red	Mouse	Jar	Gold	van	Mouth		
12	4	6-word	Son	Egg	Rat	Crow	Flag	Sweet		
13	1	7-word	Wright	Rose	Big	Stick	Jump	Blue	Tree	
14	2	7-word	Clap	Fan	Stool	Pull	Taste	Clock	Moon	
15	3	7-word	Prize	Tap	Doll	Hen	Bell	Fruit	Sky	
16	4	7-word	Bring	Roof	Sing	Duck	Pray	Gum	Book	
17	1	8-word	Ten	Stop	Eat	Test	Bus	Head	Three	Bat
18	2	8-word	White	Grass	joy	Tall	Hot	Nest	Goat	Car
19	3	8-word	Soup	Hair	Sheep	Rope	Dog	Sit	Bird	Hide
20	4	8-word	Chips	Ball	Girl	Bulb	Milk	Neck	Knife	Cake

Appendix II

Response and Scoring Sheets for APD Tests

Response and Scoring Sheets for APD Tests

[Developed as a part of the ARF project titled **'Maturation of Auditory Processes in Children aged 6 to 10 years' (2012)**]

By

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&

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General Information Form

Name: Age: ___Years____ Months

Gender: Male / Female

Name of the School:

Class studying / Section:

Medium of instruction:

Native language/Mother tongue:

Other languages known:

Handedness / laterality:

Education level of mother:

Education level of father:

Contact Phone No: Date:

Administration instructions for SPIN-IE

Transducer: Headphones
Routing of signal and noise: Monaural (Each ear to be tested one at a time)
Level of presentation: 40 dB SL (ref. PTA)
Response of child: Oral (provided child has no misarticulations)
Instruction of tester: Mark the responses as correct or wrong in the response sheet.
Scoring: '1' for each correct response and '0' for every incorrect response. Maximum score for each ear is 25.

Response Sheet
Speech-in-Noise test in Indian English (SPIN-IE)

List used:___	**Responses**	
Sl. No	**Left Ear**	**Right Ear**
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		
21.		
22.		
23.		
24.		
25.		
Total Score		

Administration instructions for Dichotic CV test

Transducer: Headphones
Routing of signal and noise: Binaural
Level of presentation: 40 dB SL (ref. PTA)
Response of child: Circles the speech sounds heard on the response sheet provided.
Instruction of tester: After the child completes the task, mark the responses as correct or wrong in the response sheet.
Scoring:

Single correct responses: '1' for each correct response and '0' for every incorrect response. The maximum score for each ear is 30.

Double correct responses: For each pair, '1' for responses correct in both left and right ear and '0' for responses incorrect in either ear or in both ears. The maximum score is 30.

Response Sheet for the Dichotic CV test

To be marked by the child		*To be scored by the tester*		
Sl. No	Responses	Single correct scores		Double correct scores
		Right ear	Left ear	
1	pa ta ka ba da ga			
2	pa ta ka ba da ga			
3	pa ta ka ba da ga			
4	pa ta ka ba da ga			
5	pa ta ka ba da ga			
6	pa ta ka ba da ga			
7	pa ta ka ba da ga			
8	pa ta ka ba da ga			
9	pa ta ka ba da ga			
10	pa ta ka ba da ga			
11	pa ta ka ba da ga			
12	pa ta ka ba da ga			
13	pa ta ka ba da ga			
14	pa ta ka ba da ga			
15	pa ta ka ba da ga			

To be marked by the child							*To be scored by the tester*		
Sl. No	Responses						Single correct scores		Double correct scores
							Right ear	Left ear	
16	pa	ta	ka	ba	da	ga			
17	pa	ta	ka	ba	da	ga			
18	pa	ta	ka	ba	da	ga			
19	pa	ta	ka	ba	da	ga			
20	pa	ta	ka	ba	da	ga			
21	pa	ta	ka	ba	da	ga			
22	pa	ta	ka	ba	da	ga			
23	pa	ta	ka	ba	da	ga			
24	pa	ta	ka	ba	da	ga			
25	pa	ta	ka	ba	da	ga			
26	pa	ta	ka	ba	da	ga			
27	pa	ta	ka	ba	da	ga			
28	pa	ta	ka	ba	da	ga			
29	pa	ta	ka	ba	da	ga			
30	pa	ta	ka	ba	da	ga			
Total score									

Administration instructions for the Duration Pattern Test

Transducer: Headphones
Routing of signal and noise: Monaural (Each ear to be tested one at a time)
Level of presentation: 40 dB SL (ref. PTA)
Response of child: Child orally labels the stimuli as ‘long’ or ‘short’, soon after hearing a triad.
Instruction of tester: The tester marks ‘LLS, SSL, etc.’ on the response sheet for each stimulus-triad. After the child completes the task, the tester mark the responses as correct (√) or wrong (X).
Scoring: ‘1’ for each correct response and ‘0’ for every incorrect response. The maximum score for each ear is 30.

Right Ear						Left Ear					
Sl. No	Child’s Responses	√ / X	Sl. No	Child’s Responses	√ / X	Sl. No	Child’s Responses	√ / X	Sl. No	Child’s Responses	√ / X
1			16			1			16		
2			17			2			17		
3			18			3			18		
4			19			4			19		
5			20			5			20		
6			21			6			21		
7			22			7			22		
8			23			8			23		
9			24			9			24		
10			25			10			25		
11			26			11			26		
12			27			12			27		
13			28			13			28		
14			29			14			29		
15			30			15			30		
Total score for the right ear						**Total score for the left ear**					

Administration instructions for the Revised Auditory Memory and Sequencing Test in Indian-English

Transducer: A loudspeaker, kept 1 meter away at 0^{o} azimuth from the head of the child.
Level of presentation: 40 dB SL (ref. PTA)
Response of child: The child is instructed to listen to each word-sequence and repeat the words heard in the same order as they were presented.
Instruction of tester: The tester marks on the response sheet, below each word sequence, numbers the correctly repeated words in the order they were repeated. Incorrectly repeated words are marked wrong (X). Any one list may be administered.
Scoring:

Auditory memory score: A score of '1' is given for each correctly repeated word. The maximum possible memory score is 118.

Auditory sequencing score: An score of '1' is given if the words are repeated in the correct order. The maximum possible sequencing score is 118.

Revised Auditory Memory and Sequencing Test (RAMST-IE) Scoring sheet– List-1

Sl No.	Token	Word Sequence	Stimuli								Mem Score	Seq Score
1.	1	3-word	Dog	Car	Rose							
Response												
2.	2	3-word	Tree	Goat	Big							
Response												
3.	1	4-word	Home	Chips	Rope	Stick						
Response												
4.	2	4-word	Blue	Nest	Rock	Step						
Response												
5.	1	5-word	Joy	Fast	Shout	Pull	Cake					
Response												
6.	2	5-word	Late	Hot	Milk	Taste	Sit					
Response												
7.	3	5-word	Grass	Train	Eat	Hair	Bank					
Response												
8.	4	5-word	Fan	Bed	Frog	Stool	Ball					
Response												
9.	1	6-word	Hide	Rich	Skirt	Run	Door	Mouth				
Response												
10.	2	6-word	Girl	Bat	Clap	White	Clock	Sweet				
Response												
11.	3	6-word	Stop	Ring	Bulb	Fish	Book	Shop				
Response												
12.	4	6-word	Mouse	Bike	Cow	Son	Grapes	Three				
Response												
13.	1	7-word	Wright	Bus	Tap	Head	Sky	Flag	Soup			
Response												
14.	2	7-word	Hut	Prize	Ten	Fruit	Jar	Doll	Roof			
Response												
15.	3	7-word	Walk	Boy	Zoo	Soap	Red	Test	Sheep			
Response												
16.	4	7-word	Bell	Chair	Tall	Fox	Bag	Hen	Key			
Response												
17.	1	8-word	Class	Rat	Sing	Plate	Cloud	Duck	Bring	Pray		
Response												
18.	2	8-word	Van	Dish	Egg	Tea	Jug	Stand	Gum	Shop		
Response												
19.	3	8-word	Desk	Eye	Blank	Knife	Toy	Sleep	Neck	Crow		
Response												
20.	4	8-word	South	Gold	Star	Cream	Cap	Bird	Kite	Jump		
Response												
Total Score												

Revised Auditory Memory and Sequencing Test (RAMST-IE) Scoring sheet– List-2

Sl. No	Token	Word Sequence	Stimuli								Mem Score	Seq Score
1.	1	3-word	Cap	Kite	Eye							
	Response											
2.	2	3-word	Tea	Jug	Shop							
	Response											
3.	1	4-word	Cream	Plate	Boy	Skirt						
	Response											
4.	2	4-word	Fish	Bike	Grapes	Rock						
	Response											
5.	1	5-word	Desk	Bank	Class	Hut	Fast					
	Response											
6.	2	5-word	Bed	Rich	Train	Step	Cow					
	Response											
7.	3	5-word	Cloud	Dish	Bag	Key	Shout					
	Response											
8.	4	5-word	Walk	Zoo	Stand	Home	Star					
	Response											
9.	1	6-word	Black	South	Door	Chair	Fox	Soap				
	Response											
10.	2	6-word	Late	Juice	Frog	Sleep	Toy	Ring				
	Response											
11.	3	6-word	Red	Mouse	Jar	Gold	Van	Mouth				
	Response											
12.	4	6-word	Son	Egg	Rat	Crow	Flag	Sweet				
	Response											
13.	1	7-word	Wright	Rose	Big	Stick	Jump	Blue	Tree			
	Response											
14.	2	7-word	Clap	Fan	Stool	Pull	Taste	Clock	Moon			
	Response											
15.	3	7-word	Prize	Tap	Doll	Hen	Bell	Fruit	Sky			
	Response											
16.	4	7-word	Bring	Roof	Sing	Duck	Pray	Gum	Book			
	Response											
17.	1	8-word	Ten	Stop	Eat	Test	Bus	Head	Three	Bat		
	Response											
18.	2	8-word	White	Grass	joy	Tall	Hot	Nest	Goat	Car		
	Response											
19.	3	8-word	Soup	Hair	Sheep	Rope	Dog	Sit	Bird	Hide		
	Response											
20.	4	8-word	Chips	Ball	Girl	Bulb	Milk	Neck	Knife	Cake		
	Response											
Total Score												