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Development, and validation of non-speech dichotic listening test

Hari Prakash Palaniswamy [a], Mayur Bhat [b, *], Rajashree Ganesh Bhat [a], Y. Krishna [c], B. Rajashekhar [a]

[a] Dept of Speech and Hearing Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal, India
[b] Dept of Audiology and Speech Language Pathology, Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal, India
[c] Speech and Hearing Unit, College of Applied Medical Science, King Khalid University, Abha, 62529, Saudi Arabia

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ABSTRACT

Background: Classic dichotic listening tests using speech stimuli result in right ear advantage, due to the dominant crossed pathway for speech and language. It is presumed that similar crossed dominance could exist for non-speech stimuli too. Hence, this is an attempt to develop and validate the dichotic non-speech test using environmental stimuli and explore the effect of focused attention on this test.
Materials and method: Three lists of dichotic stimuli were created using these sounds with fifteen tokens in each list. Four professionals and non-professionals validated these materials. Normative estimation was obtained by administering the newly developed test on 70 adults and 70 children using a free-recall and forced-recall condition.
Result: The results showed a significant difference between the left ear and right scores where the left ear score was better than the right, depicting left ear advantage (LEA) for free recall condition in both groups. In the forced recall condition, LEA was not seen; rather the mean score was significantly higher in the attended ear, irrespective of the stimuli presented to the right or left ear. The test-retest reliability in free recall was good in both the ears and moderate for forced right ear conditions.
Conclusion: The novel test consistently showed LEA with good reliability and can be used to assess the hemispheric asymmetry in normal subjects and also in test batteries for the clinical population.

1. Introduction

Central auditory processing is the perceptual processing of auditory information in the central auditory nervous system (CANS) and the neurobiological activity that underlies that processing and gives rise to electrophysiologic auditory potentials (Association, A. S.-L.-H., 2005). Dichotic listening (DL) is one of the auditory processing abilities, concerning two different stimuli presented to both ears simultaneously. Earlier research has suggested that DL processing takes place at the level of the auditory cortex (Hugdahl, 1984). Typical DL tasks require the participants to pay equal attention to both ears; however, due to the dominant crossed pathway, the signal presented to the right ear reaches language centers over the left hemisphere first, resulting in Right Ear Advantage (REA) (Kimura, 1967; Tervaniemi and Hugdahl, 2003). Hence, speech stimuli arriving at the right ear reach the Heschl's gyrus in the left hemisphere, first resulting in the right ear advantage for speech stimuli (Kimura, 1961). Further, modified instructions to focus on a particular ear increases the score in the target ear, irrespective of right or left ear. The earlier "free recall condition" represents the bottom-up processing, and the later "forced recall" condition represents top-down processing in general (Hugdahl and Andersson, 1986). The behavioral DL tests are used in the assessment of several disorders such as dyslexia, schizophrenia, Alzheimer's disease, memory loss, and central auditory processing disorder (Hahn et al., 2011; Voyer, 2011). Similarly, one can expect a left ear advantage (LEA) when a non-speech stimulus is processed in the cortex as the right cerebral cortex is specialized in processing non-speech stimuli. Previous studies using melody have demonstrated this effect in both right and left-handed individuals (Curry, 1967). In terms of reliability, some reports have suggested that during the retest, as many as 29% of individuals switched their ear advantage for dichotic speech tests and 19% for non-speech tests (Blumstein et al., 1975). Other studies on reliability have suggested that the LEA for musical stimuli is seen

* Corresponding author.
E-mail address: bhat.mayur@manipal.edu (M. Bhat).
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either for the initial items (Kallman and Corballis, 1975) or the latter items (Sidtis and Bryden, 1978) but not consistent for the entire test.

The LEA can vary with the type and complexity of the non-speech stimulus. Acoustically rich and complex non-speech stimuli like multi-tone complex and harmonic tones typically result in a high probability of LEA than simple and short-duration stimuli like pure tones (Cohen et al., 1989; Gordon, 1978; Sidtis, 1980). In terms of pure tones, the frequency of the dichotic items also affects the laterality; it is said that closer the frequencies, the higher the competition and vice versa. Thus, frequency separation is inversely propositional to laterality (Sidtis, 1981). Timber also cues LEA (Brancucci and San Martini, 1999). Participant characteristics too influence DL listening; musically trained participants showed LEA for dichotic chords but not for melodies, while individuals with no music exposure showed LEA for both these stimuli (Piro, 1993). LEA for music was greater during the menses than during the mid-luteal phase (Sanders and Wenmoth, 1998).

Literature evidence on dichotic non-speech dates back to 1960 when melodies and musical notes were used on both normals and subjects with right hemisphere lobectomy. Results revealed a left ear advantage in normal subjects and reduced scores in lobectomy patients indicating a right hemisphere preference for non-speech stimuli. There have been attempts to also assess the right hemispheric functions using words that reflect different emotions (Bryden et al., 1991; Bryden and MacRae, 1988). Results indicated a left ear advantage for emotional perception. However, musical notes as stimuli could have certain disadvantages as it lacks familiarity with excepting musicians (Kimura, 1964; King and Kimura, 1972). Hence, alternative stimuli, much more familiar than music, could be used to overcome the above limitations. If such a test is proven to be effective, it can be used across the population without language barriers in both healthy and disordered populations like learning disabilities and Right Hemisphere Damage (RHD). Further, to date, no studies on non-speech dichotic tests have focused on directed attention. Extensive work on attention effects on ear asymmetry using speech stimuli is well documented. It would be interesting to explore whether the same effect would be applicable in non-speech tests also. With this premise, the current study is aimed at developing and validating a dichotic non-speech test using environmental stimuli and also exploring the effect of focused attention on this test.

2. Method

The current observational study was approved by both the Institutional Research Committee and the Institutional Ethics Committee with reference number IEC 185/2018. The current study was carried out in 2 phases.

2.1. Phase 1: Development and validation of the non-speech dichotic test

2.1.1. Development of non-speech dichotic listening test

A total of seven commonly occurring environmental sounds viz. telephone ring (Fig. 1a and g), whistle (Fig. 1b and h), baby cry (Fig. 1c and i), cat cry (Fig. 1d and j), motorbike engine (Fig. 1e and k), cycle bell (Fig. 1f,l), aeroplane sound were chosen to develop a non-speech DL test. These selected environmental sounds were downloaded from credible sources on the internet and imported to Praat software (version 6.0). After careful inspection, the most suitable segment of the sounds was chosen by truncating around 600 msec at zero crossings to avoid the generation of clicks.

The extracted sounds were further processed in an adobe audition (version 3) for noise reduction and loudness normalization. After removing the 50 Hz hum, a noise profile was created, and the entire stimuli were scanned to remove the background noise from the whole signal. Processed signals were then group normalized to ± 3 dB.

Bruel & Kjaer, type 2250 (class I) Sound Level Meter (SLM), was used to measure the SPLs of all the stimuli. The SLM was calibrated each time before using a sound level calibrator. Sennheiser HD 206 circumaural nonstandard headphones were coupled to an artificial ear with an adaptor and, in turn, connected to SLM. LAEq values were used to measure the intensity of all the stimuli and the overall intensity ranged between 48 and 52 dB SPL.

These environmental sounds were validated by four audiologists and four adults (general population) before creating the list. They were asked to rate various parameters like intensity/loudness, duration, distortions, and naturalness on a 5-point Likert rating scale, where one being strongly agreed and five being strongly disagreeing (Table 1). After content validation, the aeroplane sound was eliminated as it had a very low score (3.5) on naturalness. Six sounds were selected, and consecutive numbers assigned to each stimulus to create a dichotic token.

A blank stereo file in the adobe audition was created, and the stimulus to be presented in the right ear was pasted on the right channel of the stereo file. Similarly, the stimulus to the left ear was pasted on the left channel. Fifty such dichotic single tokens were created in the stereo file. Two such dichotic single tokens were combined to create dichotic double tokens and a single dichotic double token consisted of four stimuli (2 presented to each ear). Silence of 1 s was inserted between the dichotic single tokens, and a pure tone signal was added to the initial segment as a carrier tone. With this arrangement, the total duration of the dichotic double token was 2.946 s. The dichotic double token is shown in Fig. 2.

A total of 45 non-speech dichotic double tokens were generated, which contained the carrier tone and the combinations of dichotic single tokens (4 stimuli). These tokens were grouped into three lists; each list included 15 stimuli. Lists were generated randomly by using the simple random sampling method. Forty-five dichotic non-speech test stimuli were allotted with numbers (1–45), and the lists were created by picking the chits.

2.1.2. Content validation of dichotic stimuli

The developed non-speech dichotic test was given to 4 audiologists and four adults (general population) for content validation. They were asked to rate the stimuli with concerning relevance from 1 to 5, 1 being strongly agreed, and five strongly disagreeing.

2.2. Phase 2: Data collection & normative estimation of behavioral non-speech dichotic test

2.2.1. Participants

A total of 140 participants were recruited for the study, comprising of 70 adults (30 males and 40 females; age range from 16 to 60 years; mean age 36.48 years) and 70 children (25 males and 45 females; age range from 10 to 15 years; mean age 12.64 years). All the participants were evaluated for the presence of hearing loss using a dual channel audiometer and only participants whose pure tone average was below 15dBHL (250 Hz–8 kHz) and no middle ear pathology (Tympanometry) were recruited. Participants were also screened for handedness using Edinberg's handedness inventory and only right-handed participants were recruited for the study. Written informed consent was obtained from the participants before their inclusion in the study.

2.2.2. Test procedure

All the participants were asked to listen to the presented sounds (each ear would receive different sounds) without concentrating on

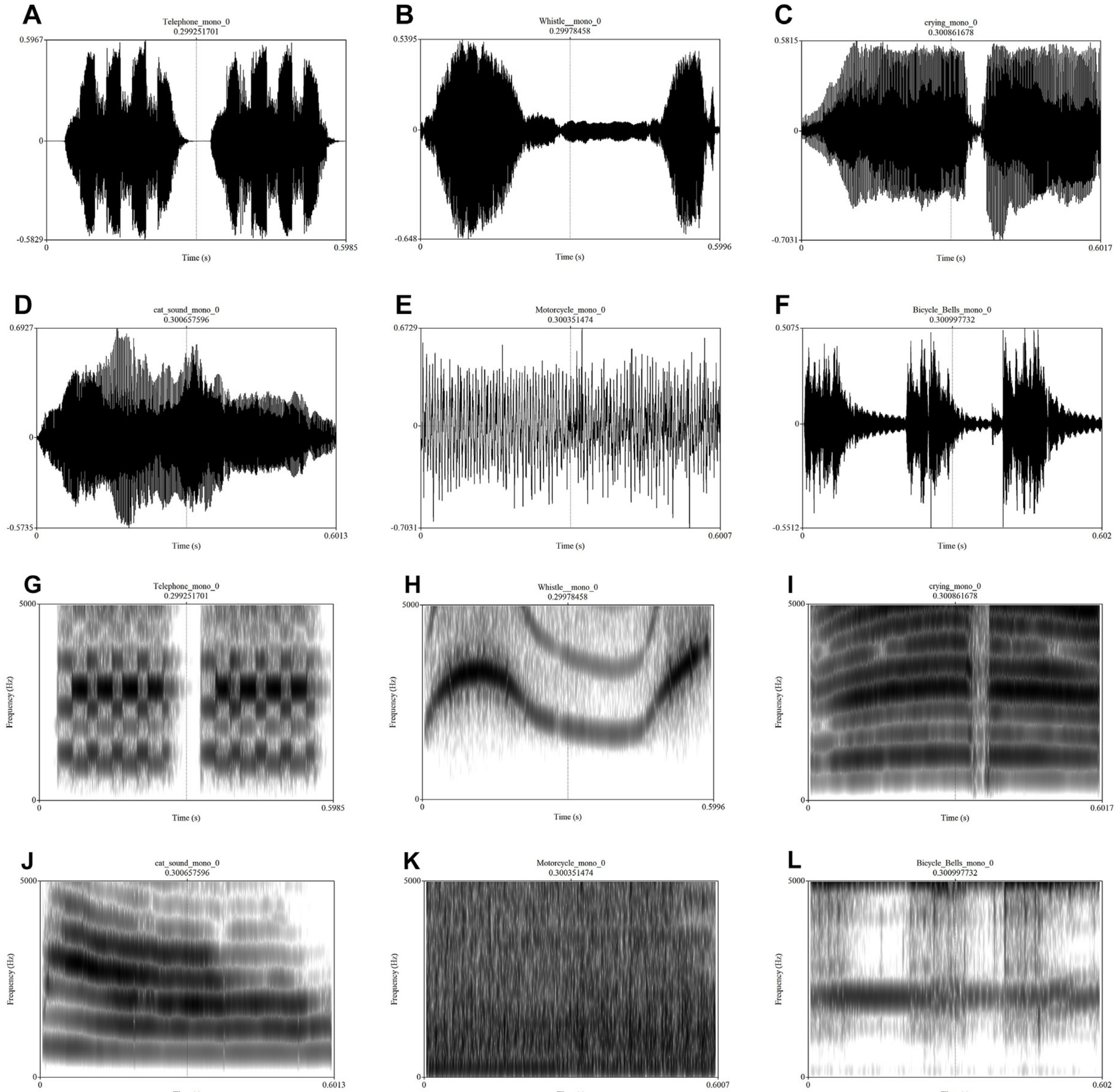

Fig. 1. Waveform and corresponding spectrogram of telephone ring (Fig. 1a and g), whistle (Fig. 1b and h), baby cry (Fig. 1c and i), cat cry (Fig. 1d and j), motorbike engine (Fig. 1e and k), cycle bell (Fig. 1f,l).

Table 1
Validation form of individual sounds.

		1	2	3	4	5
Intensity	Sound intensity is adequate for perception					
Distortion	The sound is clear and is not distorted					
Duration	The total duration of the sound is adequate to identify					
Naturalness	The naturalness of the sound					

• 1 – strongly agree; 2 - agree; 3 – undecided; 4 – disagree; 5 – strongly disagree.

any ear. A total of 2 stimuli were given to each ear and the presentation of the stimulus was preceded by a carrier tone. After they listened to all the sounds, they were asked to verbally respond by naming the sounds heard in each ear, irrespective of the order of hearing. In a forced paradigm, participants were asked to concentrate on either the right ear or left ear and report only the stimulus from the attended ear. Adequate training was given before the testing as a non-speech DL test is considered to be one of the most difficult tests and further to familiarize themselves. All the sounds were presented to the examinee before administering the actual test (individual sounds and also a few dichotic combinations).

The behavioral non-speech dichotic test was done in two paradigms, namely free recall condition and forced recall condition. A total of three conditions were assessed as described. Dichotic divided attention, which is also known as the free-recall condition where the non-speech stimulus was presented to both the ears simultaneously, and the subjects were asked to focus on the stimulus presented to both the ears. Dichotic directed attention to the

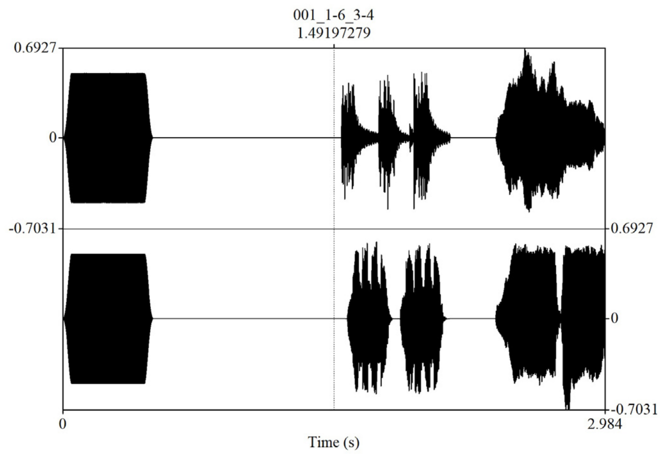

Fig. 2. A sample waveform and spectrum of a non-speech dichotic double token.

right ear, where the participants were asked to concentrate only on the right ear while ignoring the stimuli in the left ear. Vice versa, for dichotic directed attention to the left ear.

2.2.3. Scoring

"Correct recall of all the four stimuli is given as a double correct score of 1 and single correct right one and single correct left 1. Similarly, a single correct left is given 1, with right correct 0 and double correct 0, if a person recalls the responses presented in the left ear correctly and one or no stimulus presented in the right ear. Vice versa for the single correct right score. In forced recall condition, when the person recalled all the presented stimuli correctly from the attendedear, a score of 1 is given."

2.2.4. Analysis

" For validation of the developed test, the obtained scores were filled into an excel sheet, and statistical analysis carried out in SPSS (version 15) software. Scores for the questionnaire were analyzed using Cronbach's alpha test. To estimate the normative value for the developed test, a comprehensive analysis was carried out for each condition separately. Initially, the obtained scores were checked for normality using the Shapiro – Wilk test, and then the descriptive statistical analysis to estimate the mean and standard deviation. Percentile scores (5th and 95th) were calculated to generate the normative values in both free and forced recall conditions."

2.3. Phase 3: Test-retest reliability

A total of 25 participants were chosen based on the chit method to asses the test-retest reliability. The same procedure was repeated to obtain the raw scores. These scores were compared with the initial scores using Intraclass Correlation using SPSS software (version 15) for a single measure, absolute agreement, 2and -way mixed-effect model to estimate the test-retest reliability.

3. Results

A total of 7 sounds were used to make the non-speech DL test. All these environmental sounds were given to audiologists (n = 4) and the general population (n = 4) for validating the sounds.

3.1. Result of content validation

As reported by the participants, the aeroplane sound, with a score of 3.5 on naturalness, was not easily identifiable. The rest of the sounds (telephone ring, whistle, baby cry, cat cry, motorbike engine, and cycle bell) fit the validation criteria, and the results are shown in Table 2. The sounds had an acceptable level of internal consistency, as determined by Cronbach's alpha of 0.765.

Preliminary analysis was carried out to rule out the list differences which indicated that list 1 had the highest right ear scores when compared to lists 2 and 3, while there was no significant difference between lists 2 and 3. Similar findings were seen for double correct scores too. Left ear scores did not significantly differ between the lists (Table 3). Hence, list 1 was used for the free recall condition and lists 2 and 3 for the forced recall condition.

3.2. Adults

3.2.1. Free recall condition

" Shapiro – Wilk test results showed a non-normal distribution for the collected data ($p < 0.005$). Hence, the non-parametric test was used to obtain the level of significance. The Friedman test showed an overall significant difference between the four listening conditions (Free recall right, Free recall left, Forced recall right, Forced recall left) ($x^2(5) = 222.23$, $p < 0.001$).

Post hoc analysis carried out using the Wilcoxon signed-rank test showed a significant difference between left and right ear scores in the free recall condition (p = <0.05) (Table 4). As the data was not normally distributed, normative scores were constructed by calculating the fifth and the nighty fifth percentile."

3.2.2. Forced recall condition

The Wilcoxon signed-rank test showed a significant difference between forced right and left conditions ($Z = -7.184$, $p < 0.0001$). Normative values were calculated using the 5th and the 95th percentile & depicted in Table 4.

3.3. Children

" Within-subject non-parametric tests were used to check the significance as the data was non-normal ($p < 0.05$). The Friedman test showed an overall significant difference between the four listening conditions (Free recall right, Free recall left, Forced recall right, Forced recall left) ($X^2(4) = 226.5$, $p = 0.001$). Post hoc analysis carried out using the Wilcoxon signed-rank test showed a statistically significant difference between the ears for both free recall ($Z = -6.33$, $p = 0.001$) and forced condition (right Vs left) ($Z = -4.14$, $p = 0.001$). Descriptive statistics and normative values are provided in Table 5. "

3.4. Group comparision

Mann-Whitney *U* test results showed a significant group difference for left ear scores ($U = 2782.5$, $p = 0.022$) and double correct scores ($U = 2172.5$, $p = 0.001$) in free recall condition and both right ($U = 2302.0$, $p = 0.001$) and left scores ($U = 1973.5$, $p = 0.001$) in forced recall condition.

3.5. Test-retest reliability

3.5.1. Test-retest reliability for free recall condition

Test – retest reliability was calculated for left ear, right ear and double correct scores for all the 3 lists. ICC estimates and the 95% CI for right ear scores indicated a moderate to good reliability for three lists (ICC = 0.77 CI = 0.427–0.904, ICC = 0.734 CI = 0.411–0.882, ICC = 0.744 CI = 0.428–0.887). Further, left ear scores revealed good reliability for all three lists (ICC = 0.825 CI = 0.602–0.923, ICC = 0.810 CI = 0.568–0.916, ICC = 0.895 CI = 0.732–0.956) and moderate reliability for double correct scores for all three lists

Table 2
Validation of the individual sounds.

	Strongly agree –1	Agree – 2	Undecided - 3	Disagree - 4	Strongly disagree - 5
1. Telephone ring					
Intensity	5	3	0		
Distortion	3	4	1		
Duration	4	1	3		
Naturalness	4	3	1		
2. Whistle					
Intensity	8				
Distortion	6	2			
Duration	4	3	1		
Naturalness	6	2			
3. Baby cry					
Intensity	7	1			
Distortion	5	2	1		
Duration	0	6	2		
Naturalness	4	2	2		
4. Cat cry					
Intensity	8				
Distortion	7	1			
Duration	6	1	1		
Naturalness	7	1			
5. Motorbike engine					
Intensity	6	2			
Distortion	6	1	1		
Duration	3	4	1		
Naturalness	4	3	1		
6. Cycle bell					
Intensity	6	1	1		
Distortion	6	2			
Duration	5	2	1		
Naturalness	5	2	1		
7. Aeroplane					
Intensity			1	6	1
Distortion				6	2
Duration		1	7		
Naturalness				6	2

Note: Number indicates the number of subjects scored in the specific category.

Table 3
Result of Wilcoxon Signed Rank test (post hoc).

–	Z and p-value		
Lists	1	2	3
Right Ear Scores			
1	***	−4.573 (0.0001)	−6.202 (0.0001)
2	−4.573 (0.0001)	***	−2.803 (0.005)
3	−6.202 (0.0001)	−2.803 (0.005)	***
Left Ear Scores			
1	***	−1.054 (0.292)	−1.306 (0.192)
2	−1.054 (0.292)	***	−0.393 (0.694)
3	−1.306 (0.192)	−0.393 (0.694)	***
Double Correct Scores			
1	***	−5.456 (0.0001)	−6.008 (0.0001)
2	−5.456 (0.0001)	***	−2.776 (0.0005)
3	−6.008 (0.0001)	−2.776 (0.0005)	***

(ICC = 0.657 CI = 0.152–0.855, ICC = 0.734 CI = 0.400–0.883, ICC = 0.663 CI = 0.252–0.850).

3.5.2. Test-retest reliability for the forced-choice condition

The ICC estimation and 95% confidence interval calculated for forced choice condition indicated moderate reliability for forced right condition (ICC = 0.74, 95% CI = 0.114–0.914) and good reliability for forced left condition (ICC = 0.766, 95% = 0.137–0.923).

4. Discussion

4.1. Content validation

Seven environmental sounds were given to audiologists (n = 4) and adults (general population, n = 4) to evaluate the quality of the

Table 4
Descriptive statistics and normative data for Adults.

Condition	Mean (SD)	Median (Q1, Q3)	5th percentile	95th percentile
Free Recall Right	6.17 (3.123)	6 (4, 8)	1	12
Free Recall Left	10.7 (2.878)	11 (9,13)	6	14
Free Recall Double correct	3.55 (3.636)	3 (1,5)	0	10
Forced Recall Right	13.15 (1.654)	14.00 (12.00, 14.00)	10	15
Forced Recall Left	14.53 (0.731)	15.00 (14.00, 15.00)	13	15

Table 5
Descriptive statistics and normative data for Children.

Condition	Mean (SD)	Median (Q1, Q3)	5th percentile	95th percentile
Free Recall Right	5.97 (2.53)	6 (4, 8)	1	10
Free Recall Left	9.92 (2.08)	10 (9,11)	6	14
Free Recall Double correct	1.54 (1.41)	1 (0.25,2)	0	5
Forced Recall Right	11.97 (2.07)	12 (10, 13.75)	8	15
Forced Recall Left	12.98 (2.26)	14 (11.25, 15)	8	15

stimuli. Acceptable scores were obtained for all the stimuli except for the airplane. Hence, the aeroplane sound was eliminated, and six sounds were used to create three lists for the non-speech dichotic listening test. The created non-speech dichotic listening tests were validated by the audiologists (n = 4) and adults (general population, n = 4). The results of the content validation by the participants indicated appropriateness of intensity, duration, and difficulty level of the test.

4.2. Lists

The results showed comparable left ear scores for all the lists while the right ear scores differed significantly. The higher variability in the right ear could be due to the difficulty in perceiving the stimuli through the non-dominant ear. This suggests performance difficulty causing higher variability in the stimuli presented to the right ear, irrespective of the lists.

4.3. Free − recall condition

The current study results showed a classical LEA using the non-speech DL, suggesting a left ear superiority in free-recall conditions (Itoh et al., 2003; Kimura, 1964). Results of the current study highlight the right hemisphere activation for non-speech stimuli. This ear superiority effect could be due to the anatomical and physiological differences in the two hemispheres and also to the direct pathways projection from the contralateral ear to the dominant hemisphere. DL puts more demand on the hemispheres than monoaural listening. The auditory system is arranged in such a way that some of the neurons fire for ipsilateral stimulation, and some for contralateral stimulation, and few for both. A greater number of neurons are activated for contralateral stimulation, which inhibits the ipsilateral neurons (Rosenzweig, 1951).

4.4. Forced−recall condition

Compared to the free recall condition, there was a significant increase in the number of correct recalls indicating the role of attention and executive function in the dichotic forced recall test. Previous studies using dichotic speech tests have also shown the influence of attention and executive function of perceptual dominance (Hugdahl, 2003), suggesting the physiological nature of the test result. The literature on dichotic listening tests using speech stimuli has suggested greater REA for the forced right condition & decreased REA & increased LEA for the forced left condition. This is a result of different cognitive strategies used for forced right and forced left conditions (Hugdahl et al., 2009). Similar findings were obtained in the current study viz. greater LEA was seen for the forced left condition, and a greater REA for the forced right condition. The perceptual asymmetry disappeared in the forced recall paradigm.

It was interesting to note an increase of 15% in the participants obtaining maximum scores compared to free recall. Further, statistical analysis showed significant differences between the forced right and left recall conditions, with highly negligible mean difference(1.22). Considered clinically a nonsignificant difference, it could be attributed to a large sample and very small standard deviation.

4.5. Group differences

Group comparison between adults and children showed a significant difference for the left ear and double correct scores in the free recall condition where the adults exhibited statistically higher scores when compared to children. This could be an indication of a developmental trend in performance for the dichotic test. Previous studies using speech stimuli have reported that adult dichotic performance was achieved in children at around 11–12 years of age(Fuente et al., 2007). Based on the current study findings, the same can be extrapolated to non-speech tests also. Other evidence from the literature suggests that maturation of the auditory system advances well into the teenage years (Strouse et al., 1999). Higher cognitive functions like attention and executive functions will continue to develop into adolescents and early adulthood (Best et al., 2015). This could explain the lower scores in children in forced recall conditions reflecting on the age related relevance of cognitive functions like attention and executive function (Thillay et al., 2015). Hence, it can be concluded that the group differences obtained for dichotic scores could be due to the maturation of the auditory system.

4.6. Test-retest reliability

Test-retest reliability was calculated for the left ear and right ear, and double correct scores for all three lists. ICC estimates and the 95% confidence interval revealed “good” reliability for right and left ear scores across all three lists and “moderate” reliability for double correct scores for all three lists. Similarly, the forced-choice condition revealed “moderate” reliability for the forced right condition and “good” reliability for the forced left condition. Hence, based on ICC scores, it can be concluded that the developed test has “moderate” to “good” reliability for both free and forced recall conditions.

The number of tokens in each stimulus is 15, less for a classical behavioral test. Ceiling scores were obtained in the forced-recall (right and left) condition due to the above-mentioned limitation. The sample size included in the study was less as it included constructing a nomogram. The learning effect, which is a major confounder for dichotic scores, was not accounted for in the study.

5. Conclusion

A novel dichotic non-speech test was developed, validated, and administered on 70 normal adults and 70 normal children in free-recall and forced-recall conditions. In the free-recall condition, a significant left ear advantage was seen on all three lists. In the forced recall condition, with attention, the participants were able to recall all the presented sounds from the attended ear, suggesting the ceiling effect in these conditions and the ability of the individuals to switch attention between ears. The novel test consistently showed LEA with good reliability and hence can be used to assess the hemispheric asymmetry in normals and also in a test battery for clinical population such as CAPD, Alzheimer's disease, memory disorder, specific language impairment, and dyslexia.

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Declaration of competing interest

No potential conflict of interest was reported by the authors.

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