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Development and standardization of single and double dichotic digit tests in the Malay language

Desarrollo y estandarización de pruebas de dígitos dicóticos sencillos y dobles en lengua malaya

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Abstract
Single and double dichotic digit tests in Malay language were developed and standardized as an initial attempt to incorporate tests of auditory processing within the scope of audiology practice in Malaysia. Normative data under free recall, directed right-ear first, and directed left-ear first listening conditions were determined using 120 Malay children between the ages of 6 and 11 years old with normal hearing and normal academic performance. Test-retest reliability was assessed in 15 of the study subjects. In general, the double dichotic digit test produced greater differences in scores between age groups, and a greater right-ear advantage than the single dichotic digit test. In addition, the double dichotic digit test also had higher test-retest reliability. These findings suggest the double dichotic digit test is more clinically applicable.

Sumario
Se desarrollaron y estandarizaron pruebas de dígitos dicóticos sencillos y dobles en lengua malaya como un intento inicial de incorporar pruebas de procesamiento auditivo en la práctica de la audiología en Malasia. Se determinaron datos normativos en contexto abierto y en condiciones de escucha dirigidas primero al oído derecho, o primero al oído izquierdo, utilizando a 120 niños malayos con edades entre 6 y 11 años, con audición normal y rendimiento académico normal. La confiabilidad *test-retest* se evaluó en 15 de los sujetos del estudio. En general, la prueba de dígitos dicóticos dobles produjo mayores diferencias de puntaje entre los grupos etáreos, y una mayor ventaja para el oído derecho que las prueba de dígitos dicóticos sencillos. Además, la prueba de dígitos dicóticos dobles también mostró mayor confiabilidad *test-retest*. Estos hallazgos sugieren que la prueba de dígitos dicóticos dobles es más aplicable clínicamente.

Auditory processing disorders (APDs) refer to problems in the perceptual processing of auditory information by the central nervous system as demonstrated by difficulties in one or more of the following skills: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance in competing acoustic signal, and auditory performance in degraded acoustic signals (ASHA, 2005). Patients with APD often experience unusual difficulty hearing or understanding speech in various adverse acoustic and listening situations, such as listening to distorted or rapid speech, or hearing in noisy or reverberant environments, despite normal-hearing thresholds. Approximately 2–3% of children are affected by these handicapping disorders (Chermak & Musiek, 1997).

As an initial attempt to include auditory processing assessment as a part of audiology practice in Malaysia, suitable auditory processing tests that can be used to test the local population need to be constructed. A dichotic digit test (DDT), in which two different digit stimuli are presented to each ear simultaneously, is a good test to begin this exploration because it is sensitive to auditory processing abnormalities, easy and fast to administer, and is not influenced by mild to moderate hearing loss (Musiek, 1983). In addition, the limited closed-set response design makes it applicable for a wide age range of patients (Mueller & Bright, 1994).

Dichotic listening tests (DLTs) have been used to help identify breakdowns in cortical auditory function, assessing the maturation of the auditory nervous system in children and adolescents, as well as specifying the dominant hemisphere for language (Keith, 2000). The test interpretation needs to consider three parameters: the right-ear score, the left-ear score, and the ear advantage, which is defined as the overall difference in performance between the two ears. In the typically developing child, DLTs that use linguistically loaded stimuli generally yield right-ear scores that are significantly higher than left-ear scores, reflecting the left hemisphere dominance for language processing (Hynd & Obrzut, 1979). This phenomenon is referred to as the right-ear advantage (REA) (Speaks & Niccum, 1977; Keith, 2000). Nonlinguistically loaded stimuli, such as dichotic cords, produce a left-ear advantage (LEA) (Nelson et al, 2003). The magnitudes of the right-ear and left-ear scores as well as the REA depend on the linguistic content of the DLTs. Generally, the higher the linguistic level, the higher the scores. The commonly available stimuli used in DLTs in order of increasing linguistic hierarchy include consonant vowel (CV) nonsense syllables (Berlin et al, 1972; Niccum et al, 1981), digits (Kimura,

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1961, 1963, 1967; Musiek, 1983), words (Keith, 1994; Keith, 2000), and spondees and sentences (Jerger et al, 1972; Keith 1994; Keith, 2000). For most DLTs, both the right-ear and left-ear scores improve with the maturity of the auditory system. The rate of increment is faster for the left-ear score, leading to a progressive decrease in the magnitude of the REA. A minimum right-left ear difference similar to that obtained in adult subjects is achieved by the age of about 11–12 years (Keith, 2000). The REA for dichotic digit tests typically ranges from approximately 15% at 7 years of age to 2% at 11 years of age (Bellis, 1996). The REA for words decreases from around 19% at 3 years of age to 10% by 11 years of age (Keith 1986).

Three types of listening conditions have been applied in DLTs. They are free recall, directed right-ear first and directed left-ear first listening conditions. In the free-recall listening condition, test subjects are required to repeat all of the stimuli they hear in any order of preference. On the other hand, the directed listening conditions require subjects to first repeat stimuli heard in the specified ear followed by the stimuli heard in the opposite ear. Earlier studies using DLTs used a free-recall condition, (Kimura 1961, 1963, Musiek 1983). Bryden et al (1983) raised concern over this type of task as they argued performance may be affected by ear preference or selective attention, and thus may not reflect hemispheric dominance. Further, a right-handed subject may find it easier to attend to the stimuli presented to the right ear and therefore tend to have a better right-ear score. However, various studies have proven that the REA obtained in free-recall listening conditions is not solely the result of attentional bias although it is possible that such an artifact does exist. Hugdhal and Andersson (1986), for example, found that the REA was present in their subjects during the free recall as well as during the forced listening conditions, signifying the contribution of left hemispheric dominance for language processing.

Keith (2000) proposed that interpretation of abnormal DLTs be made based on:

- poor overall performance;
- reversal of ear advantage (enhanced right-ear advantage in the directed right-ear first, and enhanced left-ear advantage in the directed left-ear first listening conditions); and
- a marked left-ear advantage for both directed right-ear first and directed left-ear first listening conditions.

  Another criterion that is used to indicate APD is the presence of a larger REA and a significantly poorer left-ear score than normative values (Bellis, 1996; Chermak & Musiek, 1999).

Poor overall performance or an abnormally large REA for age indicates either a delay in maturity or a disorder of the central auditory system while reversal of ear advantage is often seen in children with learning disability (Keith, 2000). One of the theories underlying the switching of ear advantage seen in some learning-disabled children is that they suffer from a task-dependent attentional dysfunction which may interfere with left hemisphere language processing by overengaging either hemisphere (Kesrhner & Morton, 1990). A marked left-ear advantage in all listening conditions shows failure to develop left hemisphere dominance for language or damage to the left auditory cortex.

The need for developing DLT norms is crucial for the pediatric population. This is because the auditory system is undergoing maturation, thus age-specific normative values are required to help in making decisions about whether a child's auditory system is developing normally or otherwise. The availability of age-specific normative data also enables clinicians to monitor a child's performance over time. This is important in determining whether poor performance is related to a delay of maturity or a disorder of the auditory processing system. A child with a maturational delay is expected to show improvement over time whereas a child with a disorder of the auditory system will show no improvement over time (Keith, 2000).

To successfully apply the DDT in Malaysia, DDTs that use local language stimuli need to be developed and normalized. This study aims to develop and normalize single and double DDTs that use digits spoken in Malay language, as well as to assess their test-retest reliability. The normative data for the right-ear and left-ear scores, as well as the ear advantage for each test were established using 120 normal children aged 6 to 11 years. The test-retest reliability was determined by repeating the tests on 15 of the study subjects two to four weeks after the first administration of the tests.

Methods

Development of the Malay dichotic digit tests

Selection of digits

The test stimuli were made up of the digits one through eight spoken in Malay. These digits were chosen as they are all two-syllable words compared to the rest of the digits that are made up of three or more syllables.

Recording of digits

Audio recordings of the digits were completed in digital form in a sound studio using a male speaker with clear articulation using standard spoken Malay language in an accent widely used in formal speech. The speaker was instructed to say each digit five times clearly and naturally using a constant vocal effort with intervals of two seconds between utterances. This was to allow the selection of the digits that are best uttered. Three Malay speaking listeners rated the digits in terms of their clarity and naturalness of intonation. Digits that were rated highest were selected for use in the test. The digitized digit signals were then edited and equalized for overall intensity to achieve equal average levels at 0 VU$\pm$1 dB using Cool Edit Pro version 2.0 software. Overall duration of each digit was equalized to 600$\pm$10 ms by compressing or expanding the digitized digits by -15% to 15% while maintaining their intelligibility and naturalness. The digital files of digits 1, 2, 3, 4, 5, 6, 7, and 8 were edited so that the onset of the stimulus coincided with the beginning of the data file. A silent interval was added at the offset of the signal, so that the length of each digit file was equal to the longest digit duration.

Single dichotic digit pairs

The edited digit files were interleaved to form combinations of the eight digit pairs, with no digit repeated within a pair. Careful measurements were made to ensure that each dichotic set had equal onset and offset times with a deviation in duration not exceeding 10 ms. An interstimulus interval of about five seconds was added between digit pairs to function as the response time. Three different sets of 25 single digit pairs consisting of five practice digit pairs followed by 20 test digit pairs were formed. The first set was for testing in free recall, the second set for testing in directed right-ear first, and the third set for testing in directed left-ear first recall conditions.

Double dichotic digit pair sets

The double-digit pair sets were constructed by combining two of the compiled single-pair dichotic digit files, with a 500 ms silent interval between each single-pair dichotic digit. No digit was repeated within the same stimulus set. An interstimulus interval of six seconds was inserted between stimulus sets to serve as the response time. Three different sets of double dichotic digit pairs containing 25 two-pair digits (five practice pairs followed by 20 test pairs) were composed for testing in free recall, directed right-ear first, and directed left-ear first conditions each.

Preparation of the dichotic tests on a compact disk (CD)

Each member of the digit pairs was recorded on two separate channels of a CD. A specific instruction was recorded in both channels three seconds before the beginning of each digit set. For the directed listening tasks the subject was instructed to repeat all digits, repeating the digit(s) heard in the specified ear first. For the free-recall task, the instruction was for the subject to repeat both digits in any order. A 30-second, 1000 Hz calibration tone was recorded at the beginning of the tape at a level equal to the average intensity of the digits.

Normative data–subjects

Normative data were collected from Malay children 6 to 11 years old. Subjects were assigned to one of the six groups;

- 6 years to 6 years 11 months;
- 7 years to 7 years 11 months;
- 8 years to 8 years 11 months;
- 9 years to 9 years 11 months;
- 10 years to 10 years 11 months; and
- 11 years to 11 years 11 months.

One hundred and twenty subjects, 20 from each age group, were recruited from a government primary school, in Kuala Lumpur. The potential subjects were selected from the school register. Individual class teachers were requested to identify those children with language and/or behavior problems based on their observation, and those with below average academic performance. Students who were rated to have any of the above problems were excluded from the list. A list of students who would potentially be included in the study was then selected based on their date of birth and gender, to make sure that each age group was represented by an equal number of boys and girls. Parental consent was obtained before the children participated in the study. All children were then interviewed and had their hearing tested using pure-tone audiometry and tympanometry to make sure that they fulfilled the inclusion criteria.

All subjects included for the collection of normative data had:

- bilateral normal-hearing thresholds (0–15 dB HL) at frequencies 500 Hz to 8000 Hz;
- bilateral type-A tympanograms according to Jerger's classification (Jerger, 1970);
- sufficient cognitive ability to understand instructions (able to indicate right and left sides as well as able to repeat the four digits presented via live voice correctly); and
- a report from teachers indicating no language or behavioral difficulties or poor academic achievement.

Equipment

Testing was done in the school, in a quiet room, where noise level fluctuated between 40.3 and 43.2 dBA. The dichotic digit tests were conducted using a Sony CD player model CFD-G 35 equipped with two sets of stereo circumaural headphones with a frequency response of 10 to 28 000 Hz. The first headphone set was used for the test subject, and the other was for the researcher to monitor the stimulus. A Y adapter was used to connect both sets of headphones to the CD player. Each subject was tested using the single-pair and double-pair dichotic digit tests in free recall, directed right-ear and directed left-ear conditions. This test setup was used, as opposed to testing with an audiometer in a sound-proof room, because it is our intention for the DDT to be performed even in places where a sound-proof room and audiometer are not available.

Test Administration Procedure

Equipment testing was done at the beginning of each test session to ensure appropriate routing of signals, channel balancing and volume setting. The test was conducted by one of the researchers with bilateral normal hearing. The volume setting was set based on the researcher's most comfortable level (48–50 dB SL re SRT, measured using a clinical audiometer). This setting was fixed throughout the test sessions. Each subject was asked to listen to the instructions for dichotic tasks that were recorded before each set of dichotic digits on the CD. He/she was encouraged to guess when unsure of a response. Task understanding was ensured using the practice items before proceeding to the real test.

Calculation of scores for dichotic digit tests

The same scoring procedures were employed for all three listening conditions. The subject's responses were recorded on the scoring form. A correct response was allocated to each digit that was repeated correctly, irrespective of the order required. For the single-pair dichotic digit tests, the possible total correct response for each test paradigm was 20 for each ear, whereas for the double dichotic pairs the maximum score for each ear was 40.

The right-ear score (RES) and the left-ear score (LES) were calculated for each of the dichotic listening test conditions. The right-ear score was defined as the percentage of correctly repeated digits in the right ear. The left-ear score was calculated in a similar manner. The ear-advantage (EA) value for each test condition was then computed by subtracting the LES from the RES. A positive value indicates a right-ear advantage (REA), whereas a negative value denotes a left-ear advantage (LEA).

Test–retest reliability

The test–retest reliability of both single and double dichotic digit tests were examined by repeating the tests on 15 randomly selected subjects from all age groups, two to four weeks after the administration of the first test.

Analysis

To examine the effect of age on the dichotic digit tests, the resultant mean scores for the different age groups were compared using the Kruskal-Wallis test, a nonparametric test of one-way variance. The means between the right-ear and left-ear scores for each age group and each dichotic test were analyzed using the 2-tail paired t-test to determine significant differences between the two ears.

The normative data for the single dichotic digit and the double dichotic digit tests were calculated by computing the means and standard deviations for RES, LES, and EA for each test condition. Three categories of scores were developed from each of the parameters. They were normal, borderline, and abnormal. For the right-ear and left-ear scores, normal was defined as scores that were greater than 1.5 standard deviations (SD) below the mean. Borderline scores were those that fell between -2 SD and -1.5 SD below the mean, whereas scores that fell below the -2 SD were considered abnormal. For the ear advantage, normal was defined as scores that were less than 1.5 SD above mean. Borderline scores were those that fell between 1.5 SD and 2 SD above the mean, whereas scores that were greater than 2 SD above the mean were considered abnormal.

Test-retest reliability was assessed by comparing the means of scores from two testings using a paired t-test. In addition to that, test reliability was also ascertained by comparing the score categories of each subjects obtained in the first and second readministration of tests.

Results

Single dichotic digit test

The mean percent correct scores for each ear, standard deviations, mean ear difference, and their significant levels under each of the three listening conditions are summarized in Table 1.

In general, the single DDT produced mean right-ear scores that reached ceiling level with scores exceeding 95% for all age groups in all listening conditions. However, an exception was observed for the 9-year-old group in free-recall condition, in which their mean right-ear score was 92.25%. The Kruskal Wallis test showed no significant difference across age groups for the mean right-ear scores in all listening conditions ($p > 0.05$), indicating that similar high scores were obtained in all age groups. In contrast, in all listening conditions, the mean left-ear scores showed an ascending pattern with increasing age in the 6- to 8-year-old groups, after which they reached plateau levels with scores ranging from 95.75% to 98.25%. The Kruskal Wallis test showed a significant effect of age on the mean left-ear scores only in directed right-ear first listening condition ($H = 13.91$, $df = 5$, $p < 0.05$).

Table 1. Mean percentage scores by ear and between ears on the single dichotic test

Age Group (years)	*Right Mean (SD)*	*Left Mean (SD)*	*Ear Advantage (R-L) Mean (SD)*	*Sig (2 tailed) P value for R-L*
Free Recall				
6	97.00 (4.10)	90.00 (10.00)	7.00 (9.92)	0.005**
7	98.00 (3.77)	92.25 (8.19)	5.75 (0.64)	0.003**
8	96.00 (6.41)	96.75 (5.91)	−0.75 (0.89)	0.083
9	92.25 (8.19)	93.75 (7.05)	−1.50 (1.43)	0.249
10	97.00 (4.10)	95.75 (5.91)	1.25 (0.60)	0.398
11	96.75 (4.37)	96.50 (5.28)	0.25 (0.50)	0.716
Overall mean	96.17 (5.60)	94.17 (7.31)	2.04 (7.00)	0.000**
Directed right				
6	98.00 (4.70)	92.50 (8.66)	5.50 (8.87)	0.012*
7	98.75 (3.19)	94.00 (6.81)	4.75 (7.16)	0.008**
8	97.25 (4.44)	98.25 (3.35)	−0.10 (4.47)	0.330
9	95.25 (7.16)	95.50 (6.67)	−0.25 (6.38)	0.863
10	97.75 (3.02)	98.25 (4.06)	−0.50 (3.94)	0.577
11	98.00 (2.51)	97.25 (4.44)	0.75 (3.73)	0.379
Overall mean	97.50 (4.49)	95.96 (6.23)	1.71 (6.43)	0.001**
Directed left				
6	96.25 (6.26)	93.25 (9.90)	3.00 (10.18)	0.203
7	98.75 (2.22)	94.75 (8.19)	4.00 (6.41)	0.012*
8	98.50 (2.85)	95.75 (7.48)	2.75 (6.17)	0.061
9	97.25 (4.13)	95.75 (6.34)	1.50 (4.32)	0.137
10	98.50 (3.28)	97.25 (4.44)	1.25 (3.93)	0.171
11	97.75 (4.13)	96.00 (5.28)	1.75 (4.06)	0.069
Overall mean	97.83 (4.03)	95.45 (6.95)	2.17 (6.31)	0.000**

*$p < 0.05$
**$p < 0.001$

Comparison of the right-ear and left-ear scores, revealed mean REAs which were greatest in the 6- and 7-year-old groups and declined abruptly in the older groups. A significant REA was observed in the 6- and 7-year-old groups, in the free-recall condition (REA = 7.00, $p = 0.005$, for the 6-year-old group; and REA = 5.75, $p = 0.003$, for the 7-year- old group) and in directed right-ear first condition (REA = 5.50, $p = 0.012$, for the 6-year-old group; and REA = 4.75, $p = 0.008$, for the 7-year-old group). In directed left-ear first listening condition, a significant REA was only present in the 7-year-old group (REA = 4, $p = 0.012$). Directed left-ear first condition had smaller mean REAs than the other two listening conditions. REA and LEA were present in older age groups but their magnitudes were minimal. A possible explanation is that scores for both ears had reached ceiling level. The Kruskal Wallis test showed a significant difference across age groups for the mean REA in free recall ($H = 23.66$, $df = 5$, $p = 0.000$) and directed right-ear-first ($H = 14.18$, $df = 5$, $p = 0.01$) listening conditions.

Double dichotic digit test

The mean percent correct scores for each ear, standard deviations, mean ear difference, and their significant levels under each of the three listening conditions were summarized in Table 2.

Compared to the single DDT, the double DDT generally, produced more apparent increases in the mean percentage right-ear and left-ear scores, with increasing age. This improvement in scores was more rapid in the left ear than in the right ear. While the right-ear scores were similar across the three listening conditions, the left-ear scores were generally better in directed left-ear first condition. For both ears, standard deviations were greater in the younger age groups, reflecting a more variable performance. The Kruskal Wallis test revealed a significant age effect on the mean percent right-ear scores in all listening conditions ($H = 26.06$, $df = 5$, $p < 0.001$ for free recall; $F = 18.10$, $df = 5$, $p < 0.005$ for directed right-ear first; and $F = 18.27$, $df = 5$, $p < 0.005$ for directed left-ear first). A significant age effect on the mean left-ear scores was also observed in all listening conditions ($H = 43.73$, $df = 5$, $p < 0.001$ for free recall; $H = 31.07$, $df = 5$, $p < 0.001$ for directed right-ear first; and $F = 45.17$, $df = 5$, $p < 0.001$ for directed left-ear first).

Similarly, the double DDT produced greater REAs across age groups compared to the single DDT. The free-recall condition produced a significant difference between ears in all age groups ($p < 0.01$) with the exception of the 9-year-old group. The directed right-ear first condition showed significant differences between ears in all age groups ($p < 0.001$), while the directed left-ear first condition yielded significant differences between ears only in the 6-, 7-, and 8-year-old groups ($p < 0.05$). This occurred because the directed left-ear first condition produced better left-ear scores compared to other listening conditions. In general, REAs were greatest in directed right-ear first condition, and smallest in directed left-ear first condition. The REAs ranged from 0.5% to 14.13% in free recall, 5.88% to 15.00% in directed right-ear first, and 1.13% to 11.38% in directed left-ear first conditions. The Kruskal Wallis test showed significant age effects on the mean REAs in all listening conditions ($H = 25.48$, $df = 5$, $p < 0.001$ for free recall; $H = 11.46$, $df = 5$, $p < 0.05$ for directed right-ear first; and $H = 20.26$, $df = 5$, $p < 0.005$ for directed left-ear first).

Table 2. Mean percentage scores by ear and between ears on the double dichotic test

Age Group (years)	*Right Mean (SD)*	*Left Mean (SD)*	*Ear Difference (R-L) Mean (SD)*	*Sig (2tailed) P value for R-L*
Free Recall				
6	82.34 (11.82)	69.63 (14.06)	12.75 (15.39)	0.002**
7	86.00 (7.80)	71.87 (10.13)	14.13 (15.22)	0.001**
8	89.75 (7.02)	75.38 (10.43)	14.38 (10.88)	0.000**
9	83.88 (8.01)	83.38 (8.04)	0.50 (8.30)	0.700
10	90.25 (6.17)	86.25 (6.66)	4.00 (5.58)	0.005**
11	94.38 (5.31)	90.13 (7.23)	4.25 (6.18)	0.006**
Directed right				
6	83.75 (11.62)	69.00 (13.51)	14.75 (14.81)	0.000**
7	89.63 (7.58)	74.63 (8.86)	15.00 (11.75)	0.000**
8	92.38 (6.86)	79.75 (10.32)	12.63 (8.49)	0.000**
9	89.88 (7.45)	81.13 (12.45)	8.75 (10.53)	0.001**
10	92.00 (5.48)	83.50 (8.13)	8.50 (8.00)	0.000**
11	95.00 (4.29)	89.50 (5.88)	5.50 (4.70)	0.000**
Directed left				
6	82.63 (10.43)	71.50 (13.51)	11.12 (11.16)	0.000**
7	86.00 (9.91)	74.63 (9.57)	11.38 (14.34)	0.002**
8	87.75 (7.98)	81.75 (10.13)	6.00 (6.46)	0.001**
9	88.75 (7.14)	86.63 (6.85)	2.13 (5.27)	0.087
10	91.88 (6.01)	89.50 (8.09)	2.38 (7.88)	0.194
11	93.00 (6.16)	91.88 (7.20)	1.13 (6.61)	0.460

**p <0.01

Normative values

The interpretation of dichotic digit test takes into account both the right-ear and left-ear scores, as well as the ear advantage. Although, this study intended to develop age-specific normative values for both single and double DDTs, small interage differences in scores obtained in the single DDT made it impractical to either develop age-specific normative values or divide scores into normal, borderline, and abnormal. Therefore, the normative values for the single DDT were calculated based on the overall means which were obtained by collapsing the data across age groups, and classifying the scores into two categories: normal and abnormal. The collapsed mean ear scores and ear advantage for each listening condition for single DDT can be seen in Table 1. Abnormal scores were those two standard deviations below the mean. The cutoff points for abnormal scores were as follows:

- for the right-ear scores:
  - 84.97% for free recall;
  - 88.5% for directed right-ear first; and
  - 85.77% for directed left-ear first;
- for the left-ear scores:
  - 79.55% for free recall;
  - 83.50% for directed right-ear first; and
  - 81.58% for directed left-ear first;
- for ear-advantage scores:
  - 16.04% for free recall;
  - 14.56% for directed right-ear first; and
  - 14.77% for directed left-ear first.

For clinical usage, these cutoff scores were rounded off to 85% for right-ear score, 80% for left-ear score, and 15% for ear advantage. These values are applicable to all listening conditions in the single DDT.

Contrary to the single DDT, the double DDT yielded greater score differences between age groups. This enabled age-specific normative values for the double DDT to be formed. Table 3 shows the cutoff points for right-ear scores, left-ear scores, and ear advantage for each listening condition for the double DDT.

Test-retest reliability

Tables 4 and 5 summarize the mean scores of the two sessions, the mean score difference between the two sessions, their standard deviations, and the *p* values for the single and double dichotic digit tests, respectively.

In general, higher test-retest reliabilities were observed for the double DDT, in which no significant difference in scores between the two test sessions ($p > 0.05$) was observed, except for the right- and left-ear scores in the free-recall listening condition ($p = 0.00$). In contrast, the single DDT produced significantly greater results during retesting in most of its scores ($p > 0.05$). A possible explanation is that the listening task in the single DDT is easier to master and requires a lesser degree of central processing compared to the double DDT. Thus, once the subjects understand the task, their scores improve significantly. To assess how test-retest variations affect subjects' standing in score categories (i.e., normal, borderline, and abnormal), each subject's scores obtained in the two testings were compared. The results revealed that score categories remained stable for most subjects, in both the single DDT as well as the double DDT. In single DDT, only 2 of the 15 (13.3%) subjects had a different classification from the first test when retested. Both subjects moved from fail to normal. Similarly, the double DDT was highly stable, and only one subject (6.7%) had a different classification of score from the first test. In that particular child, the score moved from abnormal to borderline in the retest session. Overall, these findings indicate that both single as well as double DDTs have high test-retest reliability when interpreted using the normative values.

Discussion

This study aimed to develop and normalize the Malay single and double DDTs, as well as to assess their test-retest reliability. In general, the single DDT produced right-ear and left-ear scores, which were at or near ceiling level in all age groups, thus resulting in a small right-ear advantage. This is expected, because single dichotic digit pairs were easy to listen to, and thus did not impose an adequate challenge to the auditory system. The right-ear scores were consistently high and did not show any improvement with age. In contrast, the left-ear scores improved with increasing age, in children between 6- and 7- ear-olds, after which they became stable. This improvement in the left-ear scores reflects the maturational growth of the interhemispheric transfer system (Geffen & Caudrey, 1981; Springer, 1971). A significant REA was only found in the 6- and 7-year-old groups, in which a REA of 3% to 7% were observed. In children older than 7 years, the ear difference was similar across age groups.

On the other hand, results from the double DDT produced lower right-ear and left-ear scores, with both ears showing improvement in scores with ascending age. The right-ear scores improved from about 80% in the 6-year-old group to about 95% in the 11-year-old group, whereas an increment of scores from about 70% to about 90% was observed for the left ear. These findings, where near ceiling scores were obtained at 11 years old, are similar to those in previous studies, which show the right-ear scores to plateau at about puberty (Keith 2000). The significantly greater right-ear scores than left-ear scores, observed in the double DDT, which contain higher linguistically loaded stimuli, tallies with the concept of left hemisphere dominance for language processing proposed by Kimura, (1961) and 1963). Compared to the single DDT, the double DDT produced consistently greater REAs in all age groups (4 to 5% in the 11-year-old group to about 13 to 15% in the 6-year-old group for the double DDT; versus 0.25 to 1.25% in the 11-year- old group to about 3 to 7% in the 6-year-old group for the single DDT). The ear-advantage scores for double DDT were comparable to those of double DDT in the English language (Bellis, 1996). In general, the directed right-ear first condition yielded the largest REAs, followed by free recall, and directed left-ear first conditions respectively. Zatorre (1989) suggested that a free-recall listening condition produced higher variability in the magnitude of ear advantage, which may explain the smaller REAs obtained in the free-recall condition compared with the directed right-ear first condition. Uncontrolled attentional strategies adopted in the free-recall condition may bias a subject's responses toward either the easier right ear, or toward the more difficult left ear (Moncrieff and Musiek, 2002). Smaller REAs in the directed left-ear first condition was due to the

Table 3. Normative values for the double dichotic digit test

		Free recall			*Directed right-ear first*			*Directed left-ear first*		
Age group	*Score*	*Normal*	*Borderline*	*Abnormal*	*Normal*	*Borderline*	*Abnormal*	*Normal*	*Borderline*	*Abnormal*
6 years	Right-ear score	>64.56	58.70–64.56	<58.70	>66.32	60.51–66.32	<60.51	>66.97	61.77 –66.97	<61.77
	Left-ear score	>48.54	41.51–48.54	<41.51	>48.73	41.98–48.73	<41.98	>51.23	44.48–51.23	<44.48
	Ear advantage	<35.84	35.84–43.53	>43.53	<36.97	36.97–44.37	>44.37	<27.86	27.86–33.44	>33.44
7 years	Right-ear score	>74.30	70.40–74.30	<70.40	>72.20	60.51–72.20	<60.51	>71.13	66.18–71.13	<66.18
	Left-ear score	>56.67	51.61–56.67	<51.61	>61.34	56.91–61.34	<61.34	>60.27	55.49–60.27	<55.49
	Ear advantage	<36.96	36.96–44.35	>44.35	<32.6	32.60–38.50	>38.50	<32.89	32.89–40.06	>40.06
8 years	Right-ear score	>79.22	75.71 –79.22	<75.71	>82.09	78.66–82.09	<78.66	>75.78	71.97–75.78	<71.97
	Left-ear score	>59.81	54.52–59.81	<54.52	>64.27	59.11–64.27	<59.11	>66.55	61.49–66.55	<61.49
	Ear advantage	<30.70	30.70–36.14	>36.14	<25.37	25.37–29.61	>29.61	<15.69	15.62–18.92	>18.92
9 years	Right-ear score	>71.86	67.86–71.86	<67.86	>78.70	74.98–78.70	<74.98	>78.04	74.47–78.04	<74.47
	Left-ear score	>71.32	67.34–71.32	<67.34	>62.45	56.23–62.45	<56.23	>76.35	72.93–76.35	<72.93
	Ear advantage	<12.95	12.95–17.10	>17.10	<24.55	24.55–29.81	>29.81	<10.03	10.03–12.67	>12.67
10 years	Right-ear score	>80.99	77.91–80.99	<77.91	>83.78	81.04–83.78	<81.04	>82.86	81.04–82.86	<81.04
	Left-ear score	>76.26	72.93–76.26	<72.93	>71.30	67.24–71.30	<67.24	>77.36	73.32–77.36	<73.32
	Ear advantage	<12.37	12.37–15.16	>15.16	<20.50	20.50–24.50	>24.50	<14.20	14.20–18.14	>18.14
11 years	Right-ear score	>86.41	83.76–86.41	<83.76	>88.56	86.42–88.56	<86.42	>83.76	80.68–83.76	<80.68
	Left-ear score	>79.28	75.67 –79.28	<75.67	>80.68	77.74–80.68	<77.74	>80.08	77.48–80.08	<77.48
	Ear advantage	<13.52	13.52–16.61	>16.61	<12.55	12.55–14.90	>14.90	<11.04	11.04–14.35	>14.35

Table 4. Test-retest reliability for the single dichotic digit test

	First time (T1)		*Second time (T2)*		*T2-T1*		*T1,T2 Paired t test*
Listening Condition	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*p*
Free recall							
Right-ear score	95.00	4.22	98.67	2.97	3.67	2.28	0.000*
Left-ear score	91.33	7.90	96.00	4.70	4.67	5.16	0.004*
Ear advantage	3.67	7.19	2.67	4.17	1.00	4.71	0.420*
Directed right							
Right-ear score	96.67	4.87	99.33	1.76	2.67	4.58	0.04*
Left-ear score	96.67	4.88	97.67	3.20	1.00	5.73	0.51
Ear advantage	0.00	6.27	1.67	4.08	−1.67	7.24	0.39
Directed left							
Right-ear score	97.67	3.20	98.67	2.97	1.00	2.07	0.08
Left-ear score	92.33	5.93	97.33	3.72	5.00	5.00	0.002*
Ear advantage	5.33	5.50	1.33	2.97	−4.00	4.71	0.005*

improvement of the left-ear scores obtained during the directed left-ear first condition. This finding is similar to that of Obrzut et al (1981) and Obrzut et al (1986). This is because the right hemisphere has an inferior ability to process language, thus shifting the attention to the left ear helps to improve the score in the left ear (Ingram, 1975; Hynd & Obrzut, 1977). This postulation was supported by the findings of Obrzut et al (1986), in which they only found improvement of the left-ear scores in the directed left-ear first listening condition when using words and digits stimuli but not with CV nonsense syllable stimuli, which are known to contain minimal linguistic meaning.

Cutoff points for normal, borderline, and abnormal scores

The small interage group score differences obtained in the single DDT prevents the formulation of clinically useful age-specific normative values for that test. Consequently, common cutoff scores for all age groups were determined by collapsing the data across age groups and across listening conditions. Using these calculated values a 6- to 11-year- old child is classified as having an abnormal score when his or her score falls below 85% for the right-ear, below 80% for left-ear, and greater than 15% for the right-ear advantage. On the other hand, normative data for the double DDT were reported for the free recall, directed right-ear first, and directed left-ear first conditions as a function of age.

Test-retest reliability

The fact that the single DDT produced markedly higher test-retest variability than the double DDT was unexpected as the single DDT is less challenging than the latter. Generally, both tests yielded better ear scores during the readministration of tests, which could be explained by the practice effect (Bornstein et al, 1987). The classification of scores using the calculated normal values, however, revealed that both tests had similarly high test retest reliability.

Table 5. Test-retest reliability for the double dichotic digit test

	First time (T1)		*Second time (T2)*		*T2-T1*		*T1,T2 Paired t test*
Listening Condition	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*p*
Free recall							
Right-ear score	89.83	6.23	94.67	6.19	4.83	3.06	0.00*
Left-ear score	91.33	7.90	96.00	4.70	6.83	6.58	0.00*
Ear advantage	14.67	16.28	12.67	14.25	2.00	7.21	0.30
Directed right							
Right-ear score	92.50	4.81	95.00	4.43	2.50	7.07	0.19
Left-ear score	75.33	4.88	80.17	13.87	4.83	8.53	0.05
Ear advantage	17.17	13.43	14.83	14.98	2.33	12.59	0.49
Directed left							
Right-ear score	90.33	9.72	91.17	7.78	.83	5.32	0.55
Left-ear score	84.17	12.63	84.00	14.69	−.17	7.82	0.94
Ear advantage	6.17	15.44	7.17	13.16	1.00	10.56	0.72

Conclusions

The findings of this study revealed that the Malay single and double DDTs are likely to be useful in assessing auditory processing disorders in Malay speaking Malaysians. Double DDT is likely to be a more useful test than the single DDT because it produces clearer differences in scores between age groups, and allows for categorization of scores into normal, borderline, and abnormal. Besides this, the right-ear and left-ear scores that do not reach ceiling level even in the older age group (11 years old), makes the double DDT to be useful for wider age groups.

Future research should include reexamining test-retest reliability using a larger sample size to obtain better test-retest reliability data. In addition, the validity of the single and double DDTs in identifying auditory processing disorders could be determined by testing subjects with suspected auditory processing deficits such as children with learning disability or adults with known hemispheric pathology.

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