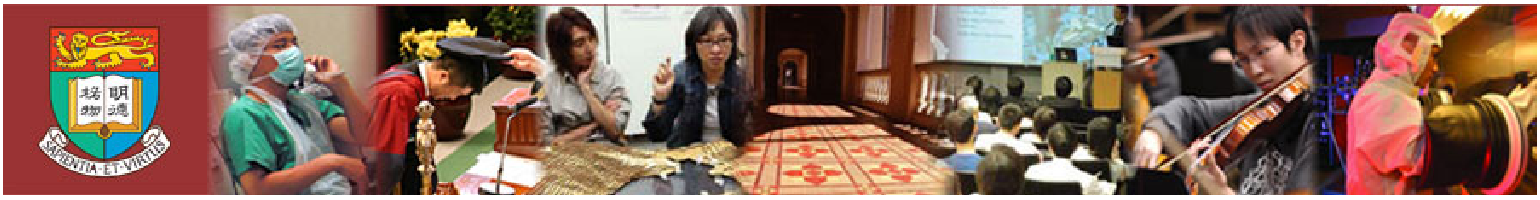

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Cantonese Dichotic Digit Test:

Normative findings for young adults

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Abstract

There is little standardised test material in Cantonese for the assessment of Central Auditory Processing Disorder (CAPD) in young adults. The dichotic digit test, which had been advocated in English language based CAPD assessment owing to its sensitivity to central auditory dysfunctions and its good test-retest reliability, was standardised for the Cantonese-speaking young adult population. Normative data were collected from 40 young adult subjects, aged from 18 to 30 years. Results were comparable to the findings from Western studies of similar speech assessment material. The CDDT's test-retest reliability and its administrative convenience make it a potentially attractive assessment procedure for CAPD cases.

Introduction

Central auditory processing includes the mechanisms and processes responsible for the following auditory events: (1) sound localisation and lateralization; (2) auditory discrimination; (3) auditory pattern recognition; (4) temporal processing; (5) auditory performance decrements with competing acoustic signals; (6) auditory performance decrements with acoustic signals (ASHA, 2005). If one or more of these processes became deficient, Central Auditory Processing Disorder (CAPD) would be the consequence. Stach (2000) claims that the deficient processes can be due to isolated neuropathology of the peripheral and central auditory nervous system (CANS), such as occur due to tumours and traumas. In addition, diffuse changes in brain function, which are typically related to aging, can also result in malfunctioning of the central auditory processes.

The CANS originates from the cochlear nucleus in the brainstem and continues to the auditory cortex. In the cortex, there is an exchange of auditory signals between the left and right hemispheres through the corpus callosum (Bamiou, Musiek & Luxon, 2001). The CANS interprets the nerve impulses generated in the cochlea (Ling, 1988). In dichotic listening, when digits are presented to the right ear, the nerve impulses are sent contralaterally to the left hemisphere via the dominant neural pathway, vice versa. The contralateral pathway, but not the ipsilateral one, was demonstrated to be dominant in the transmission of nerve impulses of dichotic materials (Kimura, 1961). Dichotic digit was firstly adopted by Kimura (1961) in the assessment of central auditory function. She demonstrated that performance deficits were common for the ear contralateral to the lesion site as a result of the dominant crossed auditory tracts, whereas reduced performance for the ipsilateral ear was reported to be negligible. Nevertheless, to preserve normal central auditory functioning, the whole processing route must be intact.

Clinically, individuals with CAPD as their only hearing disorder have normal acoustic immittance and pure tone thresholds. In other words, the hearing pathway from the outer to inner ear is basically normal. Routine audiometric examination, which is the normal procedure for identifying peripheral or sensorineural hearing deficits, cannot detect CAPD, nor do these individuals benefit from traditional hearing aids as the hearing difficulty is not due to diminished hearing sensitivity but due to higher auditory dysfunction. A common sign of CAPD is an individual complaining he or she has difficulty in hearing and understanding speech under less than optimal conditions, such as in noise. They can hear the sounds but are uncertain about what they hear. As suggested by Stach (2000), these are the functional impacts of this retrocochlear disorder. When peripheral assessment cannot identify the origin of hearing difficulty, assessing central auditory processing is of great significance owing to the serious functional consequences of CAPD on daily communication (Medwetsky, 2002).

Although there is no information regarding the prevalence for CAPD in young adults, early investigations suggested the prevalence of CAPD in the elderly was quite high. Cooper and Gates (1991) estimated that the prevalence of CAPD in elderly persons over the age of 63 to be 23 %. One can imagine how CAPD can affect modern people detrimentally in adverse listening situations, such as on the street, in transportation, attending a party, and so forth in modern life. Due to the reduced capability of listening and understanding speech in these unfavourable conditions, individuals with CAPD may not be able to function independently, for instance, in vocation and social situations where help from others may not be always available. This will undoubtedly affect young adults in particular.

To date, there are lack of standardised assessment tools and normative values of CAPD tests for Cantonese-speaking young adults that can be used by audiologists and speech therapists in Hong Kong, making identification of CAPD and prompt management difficult. All the impacts of CAPD and the need to have a clinical tool have driven this research – to develop a standardized assessment battery that can be used by audiologists, speech therapists or related professionals to assess Cantonese-speaking young adult clients.

To identify the presence of CAPD, a valid test should be able to evaluate the integrity of the CANS. There are a number of reasons a dichotic digit test was selected as the tool to be investigated. Firstly, despite the availability of advanced medical imaging techniques that are highly sensitive to CANS abnormalities, these techniques do not examine function. There have been reports that considerable CANS abnormalities have not led to identifiable central hearing deficits (Musiek & Baran, 2002). For instance, although lesions in the brainstem have been identified by medical scanning, the central auditory processing of an individual was not always affected. The opposite could also be possible, with central auditory processing deficits occurring in the absence of identifiable CANS malfunctioning. Thus, if medical imaging techniques are used extensively in the diagnosis of CAPD, a high false positive and false negative rate might be resulted. Secondly, various researchers have shown that the dichotic digit test is sensitive to the functioning of the main central auditory relating stations, such as the brainstem, cortex (Musiek, 1983), and the corpus callosum (Musiek, Gollegly, Kibbe & Verkest-Lenz, 1991). In addition to its sensitivity, the dichotic digit test is relatively resistant to mild to moderate high-frequency hearing loss (Musiek & Baran, 2002), facilitating clinical applicability for patients with concomitant mild hearing loss. Since the test employs closed-set measurement that involves only digits, it should be familiar to nearly all of the patients and thus time is saved in familiarising patients with the stimuli, and failed performance could hardly be attributed to the stimuli. As dichotic listening is seldom experienced in daily situations (Strouse, Wilson & Brush, 2000), learning and practice should not be possible prior to receiving the test. This means the performance deficits in the dichotic digit test are not task related but owing to auditory deficiency or other factors. Furthermore, the dichotic digit test is simple and quick to administer, which is very important for clinical feasibility. Lastly, high test-retest reliability for the dichotic digit test had also made the test appealing in testing English-speaking adults (Musiek, Gollegly, Kibbe & Verkest-Lenz, 1991).

'Dichotic' refers to parallel presentation of two different speech materials to both ears. In this study, double digits were chosen rather than single digit since Noffsinger, Martinez and Wilson (1994) indicated that single dichotic digit test would consistently produce ceiling performance in normal-hearing individuals. A dichotic digit test can be administered in free-recall or directed (left and right) recall conditions. In the present study, both conditions were used so as to derive more information for the normative data. In the free-recall condition, the subject is required to recall the four digits (2 pairs of double digits) heard, irrespective of order. Musiek (1983) proposed that adults with normal hearing should score at least 90% correct (2 standard deviations below the mean) for both left and right ears in the free-recall condition. In directed listening conditions, the subject is required to recall the two digits heard from the assigned ear. For example, if it is a directed-left ear condition, the individual has to recall only the digits heard from the left ear, or alternatively, some researchers require subjects to recall the digits from the left and then right ears. Currently, normative data are not available for the directed recall conditions. Therefore, the present study would like to obtain normative data for Cantonese-speaking young adults under free-recall condition, and make a comparison with the results obtained from western populations.

Digits are linguistic in nature. A majority of humans are right-handers and, applying the phenomenon of left cerebral dominance of language (Mueller & Bright, 1994), they process linguistic stimuli predominantly in the left hemisphere. Research has demonstrated that the degree of handedness is significantly associated with the side of language dominance (Knecht, Drager, Deppe, Bobe, Lohmann, Floel, Ringelstein & Henningsen, 2000). This implies one’s handedness may indicate his or her dominant hemisphere for language processing, including digits processing. Similarly, Stach (2000) claims that if the testing stimuli are generally linguistic, most individuals will experience a Right-Ear-Advantage (REA), which will be more obvious in patients with an impaired corpus callosum and auditory cortex due to inter-hemispheric processing inefficiency. When linguistic materials are presented to both ears simultaneously, the nerve impulses are crossed to the contralateral hemisphere. The dominant left hemisphere will then process and interpret linguistic messages immediately, but the right hemisphere will not. The nerve impulses carrying linguistic materials crossed to the right hemisphere need to be transmitted to the left hemisphere via the corpus callosum for complete processing, and thus processing and interpretation is less efficient. Therefore, it is reasonable to hypothesize that right-handed normal-hearing adults, who are supposed to show left hemispheric dominance of language, might obtain higher scores in the right than the left ear, supporting the REA phenomenon. On the contrary, Bellis (1996) put forward that REA is apparent in young children because of their developing corpus callosum, in which myelination is yet completed, and that the REA decreases as age increases. This hypothesis may be supported by the findings of Musiek and Baran (2002) that ear differences, if they exist, are very small, particularly in young adults. Strouse and Wilson (1999) asserted that REA is large only when more difficult three or more pairs of digits are used in dichotic tasks. An interesting finding by Yury et al. (1998) was that in a quiet environment, speech is generally processed in the dominant left hemisphere, while in a noisy environment the contribution of the right hemisphere increases but that of the left hemisphere is noticeably reduced. Since listening with noisy backgrounds and dichotic listening both reflect auditory performance with competing acoustic signals, it may be hypothesized that speech may not be dominantly processed in the left hemisphere at all times, particularly in situations with competing acoustic signals. Therefore, to have a preliminary conclusion on this issue, another purpose of the present study was to investigate whether an ear advantage does or does not exist in Cantonese-speaking young adults.

The aim of this paper was to describe a standardised test, the Cantonese Dichotic Digit Test (CDDT), for young adults. The results are analysed and discussed in terms of:

1. Normative data for the CDDT in three listening conditions (free-recall; directed-left ear recall; directed-right ear recall);
2. Differences in listening performance with reference to the effects of age and gender;
3. Presence of ear difference to observe if normal hearing adults have a particular ear that performs significantly better than the other;
4. Test-retest reliability of the CDDT to ensure clinical utility;
5. The clinical implications of the CDDT (i.e., clinical applicability for audiology and speech therapy, and the future directions of CDDT research).

Method

Subjects

Forty-four Cantonese-speaking young adults from 18 to 30 years old participated in this research. They all were right handed as checked by the Edinburgh Handedness Inventory (Oldfield, 1971). The number of male and female subjects was equal. To ensure the subjects recruited were of normal peripheral and central auditory functioning, the screening procedures and subject inclusion criteria noted in Table 1 were adopted:

Table 1: Screening procedures and subject inclusion criteria

Screening procedure	**Subject inclusion criteria**
1. Otoscopic examination	Sullivan Scale of 0, +1, +2 (Sullivan, 1995)
2. Acoustic immittance measures	Passed the ASHA (1996) criteria (Appendix A)
3. Audiometric screening at 25dB	Passed all of the frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz
4. Amsterdam Inventory for Auditory Disability and Handicap (Kramer, Kapteyn, Festen & Tobi, 1995) - Cantonese version (Yim, 2003) (Appendix B) identifying those who have suspected CAPD or hearing deficit	Rated less than two questions as ‘occasionally’ or ‘almost never’; and all other questions as ‘always’ and ‘usually’
5. Medical history	Negative history for otological or neurological disorders (i.e., middle ear infection, neural surgery)

Four subjects were excluded from this study as they failed to fulfil the ASHA criteria concerning the peak value or tympanic width in immittance tympanometry. The remaining forty subjects all passed the above criteria and consented to participate in this research (Appendix C for the consent form). The subjects were divided into two age groups. Table 2 lists the subject details.

Table 2: Subject detail summary

Age group	Average age (Yr)	Number of subjects	Education level
(1) Age 18 to 23	20.4	N=20	Secondary school
		(Male=10; Female=10)	to tertiary level
(2) Age 24 to 30	26.0	N=20	Secondary school
		(Male=10; Female=10)	to tertiary level

Test-retest reliability of a clinical test is very important, particularly when monitoring the changes experienced by patients over time. Hence, twenty-five per cent of the subjects were randomly selected to take part in the test-retest reliability check four weeks after the administration of the first test. They were informed of the test-retest schedule at the time of the first test, and all consented to participate in the second test.

<u>Materials</u>

Screening procedures

A Cantonese version (Yim, 2003) of the Amsterdam Inventory for Auditory Disability and Handicap (Kramer, Kapteyn, Festen & Tobi, 1995), which was translated from the English version of the questionnaire, was used as one of the screening procedures. It was adopted because the signs of peripheral and central auditory dysfunction were objectively illustrated in everyday hearing situations. For instance, information on discrimination of sounds, auditory localization, speech comprehensibility in noise and quiet, and detection of sounds was gathered by the questionnaire. Therefore, this questionnaire could be used to screen out subjects who were suspected of possible peripheral or central hearing deficits. Apparatus employed in the screening of outer and middle ear functioning included a manual otoscope for otoscopic examination, a tympanometer for immittance audiometry, a standard pure-tone audiometer for audiometric screening, and a clinical audiometer for playing the Cantonese dichotic double-digits test that was developed by Fuente and McPherson (2005).

Information regarding handedness

Since handedness has been significantly related to the side of hemispheric dominance in language (Knecht et al., 2000), the Edinburgh Handedness Inventory (Oldfield, 1971) was applied to all the subjects to confirm their handedness, so that the subjects' dominant hemisphere for language processing could be roughly estimated. Such information could be used to explain the ear difference, if present, in dichotic listening.

Cantonese Dichotic Digit Test (CDDT)

The compact disc for the CDDT was obtained from the project supervisor of this research. Seven digits (2 - /ji6/, 4 - /sei3/, 5 - /m5/, 6 - /luk6/, 7 - /tsʰɐt1/, 8 - /pat3/, 9 - /kɐu2/) with no repeated digits within the double-digit pairs were used to generate three sets of stimuli in three separate CDs; each set consisted of twenty randomised double-digit pairs. The digits were selected in a way to maximise the perceptual contrast among the digits, thus confusion to listeners was kept minimal. From all the selected digits, their initial consonant, vowel and diphthong appeared only once, and the digits having the same tone would differ in both onset and rime. Another practice CD included a 1 kHz tone for the calibration of the clinical audiometer that had to be done before the start of the test, and the three practice trials for each listening condition. The three listening conditions were randomly assigned to the three sets of stimuli to counterbalance the sequence of stimuli with reference to the sequence list (Appendix D). The seven digits used were distributed evenly within and among the three sets. The presentation of each digit pair was randomised using the ‘shuffle’ function in the CD player. Before the start of each trial, a preparation alert “請準備” (Please get prepared) was presented. Under normal circumstances, repetition or pausing during the test was not allowed unless the clarity of the digits was affected by extrinsic factors, for example, the electromagnetic disturbance due to a mobile telephone affected the operation of the audiometer. The inter-digit pair interval was fixed to be 0.5 second and that of inter-trial was 5s.

Procedures

All measurements took place in the Hearing Centre of Prince Philip Dental Hospital, the University of Hong Kong. Participants were explained the details of this research, and consent was obtained from each of them. The participants were asked to complete the Cantonese version (Yim, 2003) of the Amsterdam Inventory for Auditory Disability and Handicap (Kramer, Kapteyn, Festen & Tobi, 1995) on their own and any misconceptions were clarified. If the participants rated more than two questions as ‘occasionally’ or ‘almost never’, they relevant questions would be explained once more to ensure they had not misunderstood them. Following the questionnaire the case history taking, and otoscopic and tympanometric examinations were conducted. Information about mother tongue, medical and health status, and handedness was obtained in the case history (Appendix F). Pure-tone audiometry (PTA) and the CDDT were administered in a soundtreated room in the University of Hong Kong Hearing Centre. PTA was performed after the completion of the above procedures; tone was presented twice at each frequency in the sequence 1000 Hz, 2000 Hz, 4000 Hz and 500 Hz. Any participant who had failed one or more of the above screening procedures did not proceed to the dichotic listening test.

To verify the handedness of the participants, the Edinburgh Handedness Inventory (Oldfield, 1971) was used, and a laterality quotient was calculated for each participant by asking their hand preference in writing, drawing, throwing an object, and for using a toothbrush and a spoon (Appendix G). It is suggested that strong right-handedness corresponds to a laterality quotient of higher than 75 (Oldfield, 1971). All the participants had the laterality quotient above 75, indicating they were strong right-handers.

In the dichotic listening task, the double-digit stimuli were presented at 60 dB HL. Each participant attempted three practice trials before the start of each sub-test (free-recall; directed-left; directed-right) to ensure familiarity with the testing procedures and to control any practice effects (Bellis, 1996). All participants took part in the free-recall condition first to minimise any biased hearing effect. For instance, if directed-left condition had been presented to the participant prior to the other two conditions, he or she might tend to use the left ear in listening in the subsequent listening conditions (i.e., free-recall and directed-right conditions). Instructions were given for a second time if the participant was unsure about the procedure. In the free-recall condition, the participants listened to simultaneous presentation of two double-digit pairs in Cantonese, such as “five, nine” from the left ear and “four, two” from the right, and they had to repeat the digits heard irrespective of order and ear into a microphone. The investigator, who is a native Cantonese speaker, manually scored their performance. There were two directed recall conditions, one was directed-left and the other directed-right. In the directed-left condition, the participants needed to report the digits heard from the left ear only; he or she might ignore the digits heard from the opposite ear, and vice versa for the directed-right listening. The participants were informed of their general performance of the whole test orally (e.g., with the researcher stating that “according to Western literature, his or her hearing ability for this task was within the normal range”). Any queries from the participant concerning this research or their hearing performance were then answered.

Results

Statistical Results

Descriptive statistics were used to demonstrate the mean correct scores for each ear, standard deviations, and the mean right ear advantage under the three listening conditions (Table 3).

Table 3. Mean correct scores (maximum score = 40) under the three listening conditions.

	Right	**Left**	**Right Ear Advantage (R-L)**
Age Group	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Free-recall			
18-23	39.55 (0.83)	39.60 (0.82)	-0.16 (1.51)
24-30	39.35 (0.93)	39.70 (0.92)	-0.25 (2.60)
Dir-L			
18-23	-	39.05 (1.23)	-
24-30	-	39.45 (1.10)	-
Dir-R			
18-23	39.50 (0.83)	-	-
24-30	39.70 (0.47)	-	-

The mean scores obtained in each ear and listening condition reached ceiling level, with scores higher than 39 (total score = 40), which was equivalent to 97.5% correct or above. The results were comparable to the study by Strouse, Wilson and Brush (2000) using young adults of 20 to 29 years of age, in which 96.3% and 98.8% correct scores were found in the free-recall conditions for the left and right ear, respectively.

To examine the effect of the two independent variables, age and gender, on the mean ear scores and REA in all conditions, the non-parametric Mann-Whitney U-test was used. $P<.05$ was considered statistically significant. Table 4 summarizes the statistical results in terms of age and gender groups.

Table 4. Statistical results of the age and gender groups

	Right ear			Left ear			Right Ear Advantage		
	Statistic value (U)	N	p-value	Statistic value (U)	N	p-value	Statistic value (U)	N	p-value
Free-recall									
Age	177.00	20	.53	180.50	20	.60	171.00	20	.43
Gender	143.00	20	.30	162.00	20	.12	173.00	20	.47
Dir-L									
Age	-	-	-	162.00	20	.30	-	-	-
Gender	-	-	-	188.50	20	.76	-	-	-
Dir- R									
Age	184.00	20	.67	-	-	-	-	-	-
Gender	172.00	20	.45	-	-	-	-	-	-

There was no significant difference in the scores and ear difference in terms of age and gender groups, suggesting the performance did not vary significantly among the young adult subjects. In free-recall condition, the age group consisting of 18 to 23 year-old-adults showed more comparable performance in both ears, whereas the age group of 24 to 30 year-olds performed slightly better in the left ear (Figure 1), although these differences were not statistically significant.

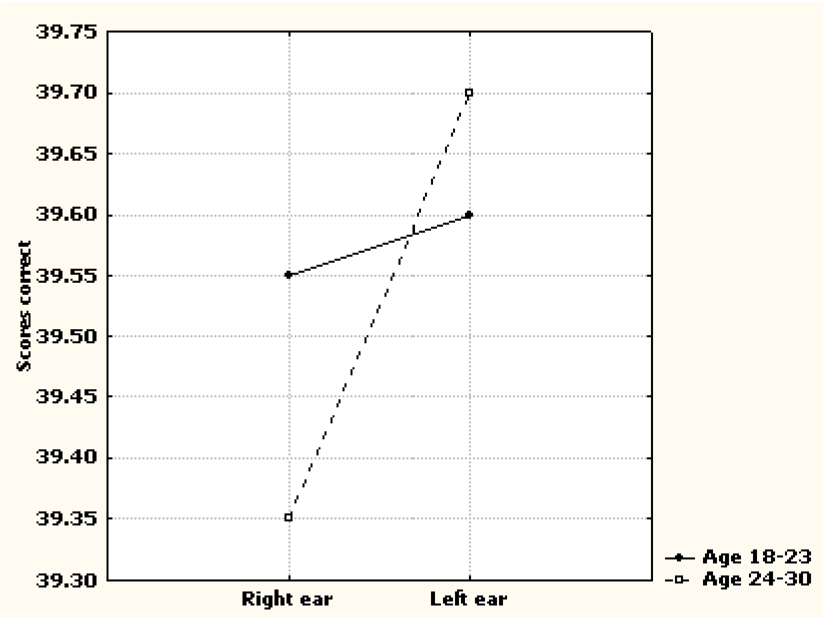

Figure 1. The mean scores of the two age groups for the free-recall condition.

The Wilcoxon matched pairs test was used to determine if significant difference was present between (1) the left and right ears in free-recall; (2) the left ear scores in free-recall and directed-left conditions; and (3) the right ear scores in free-recall and directed-right conditions (Table 5).

Table 5. Statistical results on the pairs of dependent variables.

Pairs of variables	Wilcoxon matched pairs test (T)	p-value
(1) Free L ear & Free R ear	26.00	.17
(2) Free L ear & Directed-left L ear	21.00	.05*
(3) Free R ear & Directed-right R ear	109.50	.39

*p=.05

There was no significant difference between the left and right ears in the free-recall conditions (T=26.00, p>.05), suggesting the ear advantage phenomenon was insignificant in the present group of subjects. However, statistically significant results were identified in the left ear scores between the free-recall and directed-left conditions (T=21, p=.05) but not when comparing the right ear scores in free-recall and directed-right conditions (T=109.5, p>.05). This suggested the directed listening condition was generally more difficult to the left ear.

Development of normative values

Normative values were developed for clinical use. Since the Mann-Whitney U-Test did not reveal any statistical difference in the scores between the age and gender groups respectively, the norms were not categorized according to age and gender. The mean values of each ear in all listening conditions were at the ceiling level (Figure 1); the minimum scores in the left and right ear in both free-recall and directed listening conditions were 36 and 37, respectively. The maximum score was obtained from 40th percentile onwards for the right ear in both conditions and the left ear in the directed-left condition, whereas the performance in the left ear free-recall reached plateau at its 20th percentile. Based on the cut-off criterion that had been devised by Musiek (1983) and

Musiek, Gollegly, Kibbe, and Verkest-Lenz (1991), 2 standard deviations below the mean was used to establish the normal cut-off scores for each listening condition. Table 6 shows the mean score, standard deviations, cut-off scores, maximum and minimum scores, and percentile scores for ear performance and the REA for all entire test conditions, irrespective of age and gender. The mean scores and one standard deviation below and above the means were shown graphically in Figure 2.

Table 6. Normative data for Cantonese Dichotic Speech Test

	Mean (N=40)	S.D.	Cut-off score	Max.	Min.	Percentile scores									
						5th	10th	20th	30th	40th	50th	60th	70th	80th	90th
Free-recall															
Left ear	39.65	0.86	37	40	36	37.5	39	40	40	40	40	40	40	40	40
Right ear	39.45	0.88	37	40	37	37.5	38	39	39	40	40	40	40	40	40
^REA	-0.50	2.13	-	5	-7.5	-5	-2.5	-2.5	0	0	0	0	0	0	1.25
Dir-Left															
Left ear	39.25	1.17	36	40	36	37	37	38	39	40	40	40	40	40	40
Dir-Right															
Right ear	39.60	0.67	38	40	37	38.5	39	39	39	40	40	40	40	40	40

^ REA (Right Ear Advantage) = R-L. The more positive the number, the more significant the REA.

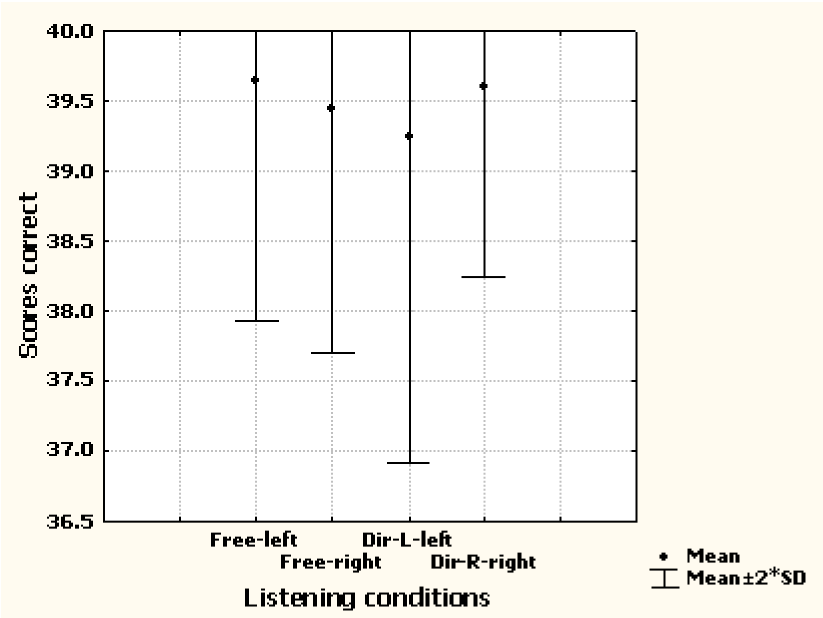

Figure 2. Mean scores on the CDDT. Two standard deviations are shown by the vertical lines.

Test-retest reliability

To study the test-retest reliability of the Cantonese Dichotic Digit Test, twenty-five percent of the subjects were randomly selected. The test was re-administered four weeks after the first trial. The reliability of the CDDT was analysed using the Wilcoxon matched pairs test and also by considering the absolute difference values between the two performances. Due to the ceiling effects, the non-parametric Wilcoxon test was used to determine if the means obtained in the two trials differed significantly. Results (Table 7) showed that the mean scores obtained in test and retest conditions did not differ significantly in magnitude ($p>.05$). The similar mean values revealed that subjects performed more or less consistently in both tests. This was evidenced by the comparable trends shown in the test-retest scores for each subject (Figure 3).

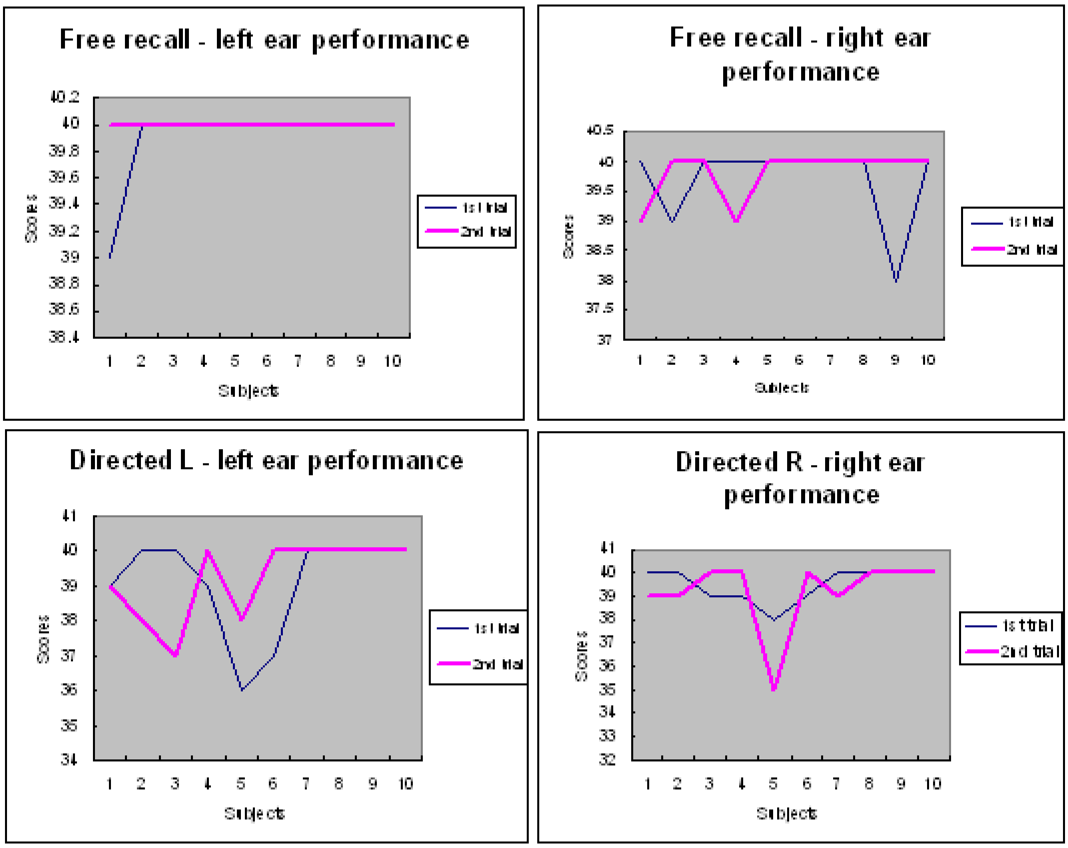

Figure 3. Cantonese Dichotic Digit Test test-retest scores for the ten subjects

Table 7. Test-Retest Reliability for Cantonese Dichotic Digit Test

	Trial 1 (T1)		Trial 2 (T2)		T2-T1		Wilcoxon test	
Condition	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**T**	**p**
Free-recall								
Left ear	39.90	0.32	40.00	0.00	0.10	-0.32	1.60	.11
Right ear	39.70	0.67	39.80	0.42	0.10	-0.25	0.37	.72
REA	-0.5	1.97	-0.5	1.05	0.00	-0.92	0.00	1.00
Dir-L								
Left ear	39.10	1.45	39.20	1.14	0.10	-0.31	0.13	.89
Dir-R								
Right ear	39.40	0.70	39.20	1.55	-0.20	0.85	0.31	.75

Apart from the Wilcoxon test, agreement of the test-retest results demonstrated the CDDT had good reliability. The agreement was measured by taking the absolute value of the score difference between the two trials without considering the sign (+/-). Table 8 and figure 4 show the absolute value in each ear and test condition.

Table 8. Absolute value of the performance difference between test and retest.

Absolute value	No. of subjects having the absolute value			
	Free-L	Free-R	Dir-L	Dir-R
0	9	6	5	3
1	1	3	1	6
2	0	1	2	0
3	0	0	2	1
Total no. of subject	10	10	10	10

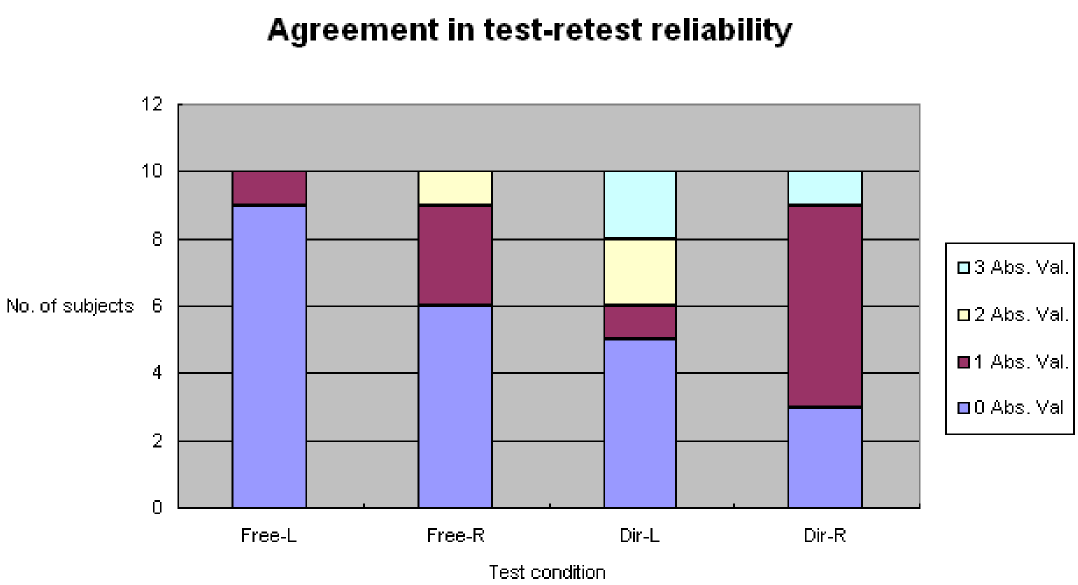

Figure 4. Agreement on the CDDT using absolute values between the test and retest trials.

Comparing the mean scores, trend, and agreement between the test and retest results, it is clear that majority of the subjects performed identically or, to a lesser extent, showed a one-point difference. These results indicated a high consistency between the test and retest conditions.

Summary of findings

Results showed good test-retest reliability. Most of the young adult subjects performed at ceiling level. No age or gender difference existed in any test conditions. There was no significant ear advantage in the free-recall condition.

Discussion

The normative values for a standardised CAPD test, the Cantonese Dichotic Digit Test, for young adults and its test-retest reliability were determined. Results obtained in the present study were similar to those found in previous research with dichotic digit test using English-speaking young adults.

The present study derived normal cut-off scores for the CDDT. In free-recall condition, the cut-off scores for both left and right ears were 37 (92.5%), whereas those for directed-left left ear and directed-right right ear were 36 (90%) and 38 (95%), respectively. These scores were comparable to the western studies (Musiek, 1983; Strouse, Wilson & Brush, 2000). Therefore, if a score was below the cut-off scores, the patient failed the CDDT, and CAPD should be suspected.

No significant difference was found between the two gender groups and the two age groups. This was expected because there have been no research findings that demonstrate the presence of significant gender effects on dichotic listening, nor had the within young adult age groups shown variance. However, Strouse, Wilson and Brush

(2000) noted that their young adult group and their elderly group did differ significantly in the double-digits free-recall condition. Further research on comparing young adults and the elderly on dichotic listening would shed light on this possible performance difference in Cantonese-speaking individuals.

The two age groups performed at ceiling level in all the listening conditions and no significant difference in listening performance was found between the two groups. Although the dichotic listening situations were unfamiliar to the subjects, the level of difficulty presented little challenge to them, resulting to the expected ceiling levels.

The ceiling performance in the CDDT might be one of the reasons contributing to the insignificant ear difference and thus the ear advantage. Similar findings had been reported in Jerger, Alford, Lew, Rivera and Chmiel (1995) that the REA is typically small if it is found in young adults, infrequently exceeding 5%. The normative data provided by Bellis (1996) also suggest the ear difference, which is commonly seen in children, would not be significant in the adult population. This is because the development of the CANS should be completed by adulthood. A slight left ear advantage found in the free-recall condition was less common in earlier studies, but such phenomenon in normal right-handed adults was documented previously by a number of researchers (Strouse & Wilson, 1999). Thus, the normative values obtained in the present research are consistent with the findings from the previous studies that the present study supports previous researches that have demonstrated that REA is insignificant in normal young adults. Whether REA does exist in children, elderly or brain-damaged patients requires further research.

There are two directions for further research. The first one is to minimise the ceiling effects while the second is to standardize the CDDT with patients with CAPD. The ceiling effects in normals could be minimised by several ways. Firstly, the difficulty of the test stimuli could be increased. The present study utilised double digits as the test stimuli. Strouse and Wilson (1999) suggested that when level of difficulty increases, ear advantage would become more obvious due to the dropped ceiling performance. Using triple (2 pairs of three digits), or even four-pair digits should be useful to minimise the ceiling effect and the same time, avoid the floor effect. Further, Strouse and Wilson (1999) had demonstrated that uncertainty of stimuli length, in which single, double, triple or even four-pair digits were randomised and presented in a single test, but the subject was not certain about the number of digits prior to presentation, could reduce the ceiling effect and increase the REA. Therefore, both the number of digits and the uncertainty might be employed in further investigations.

In addition to the level of difficulty, the education background of listeners might add to the ceiling effect. Over 75% of the subjects in the present study had tertiary education. The range of education level might not be diverse enough, thus the subjects recruited might not be as heterogeneous as the entire population. It is recommended that replications of related research should recruit subjects from wider education background, for instance, ranging from primary to tertiary education.

Another contributing factor to the ceiling effects could be related to the attention level of the subjects. Hugdahl, Law, Kyllingsbæk, Brønnick, Gade and Paulson (2000) have demonstrated that attention generally facilitates auditory processing, and divided attention is essential in dichotic listening. This view is supported by Medwetsky (2000) who found that the demand for divided attention increases as the level of difficulty in dichotic listening increases. It is plausible that the subjects in this research might have relatively good attention skills, particularly divided attention. It would be interesting to look at future investigations that manipulate attention as one of the variables and then study the effects of this factor.

Besides minimising the ceiling effects, it is recommended that further investigations involve the standardization of the CDDT using subjects with CAPD. This will provide valuable information of whether appealing sensitivity of the dichotic digit test is also present in the Cantonese speaking population. Since the present study had demonstrated that normals cluster around 95% correct, and if majority of the cases with CAPD show scores much less than 95% correct, it implies good sensitivity of the CDDT.

The good test-retest reliability indicated that the CDDT is a reliable assessment tool for CAPD. The consistency of the test means it would be suitable for monitoring patients' hearing performance over time. This is particularly important for those patients whose aetiology is progressive in nature, because when hearing performance keeps deteriorating, the patients' needs may change accordingly. Professionals such as speech therapists or audiologists can estimate the functional impacts resulting from the CAPD, and an individualised management programme can be provided.

Other benefits of the CDDT include the ease of administration and scoring, which enables professionals to be become familiar with the procedures within a short period of time. No subjects indicated confusion with the test method and all of them could understand what they were required to do in the test after the three practice trials in each listening condition. Time was saved as no re-instruction was needed. The whole CDDT procedures, including the instructions and the practice trials, took about ten minutes for each subject. If the clinician administers only one of listening conditions, such as the free-recall condition, as a screening procedure of CAPD or due to time constraints, the time needed will be even less - about three minutes.

There are many times that one CAPD test alone is inadequate. Mueller and Bright (1994) suggested that a variety of tests give more convincing evidence about a patient's performance deficits than one test does, especially in the borderline cases. Thus, if an individual showed abnormal performance in various CAPD tests, the diagnosis of CAPD could be more confidently made. Besides, Bamiou, Musiek and Luxon (2001) put forward that in cases where the central auditory dysfunction is associated with more pervasive processes, such as the involvement of cognition, the diagnosis of CAPD is multidisciplinary since the pervasive processes may intertwine with other sensorimotor functioning and cognition processes. A careful consideration of cognitive, memory, and linguistic factors will be necessary.

Conclusion

The present study investigated the Cantonese Dichotic Digit Test and found normative results comparable to Western studies for young adults. No significant age, gender, or ear effects were noted. The CDDT serves as a reliable and convenient assessment tool for Central Auditory Processing Disorders.

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Appendix A, ASHA criteria *

PASS/FAIL criteria for Screening Battery

1. Medical History

Fail criteria:
- A. Behavioral Disorders
- B. Mental Deficit
- C. Neurological Problem
- D. Brain / Ear Surgery
- E. Under regular medication
- F. Long Term Middle Ear Infection
- G. Affecting psychological and cognitive status

2. Mother Tongue

Fail criteria: Non-Cantonese speaking; other dialect accents

3. Otoscopy

Cerumen scale:

0 : Cerumen entirely absent / present in a small amount

+1 : Non-occlusive minor amounts present, TM essentially visualized (Removal optional)

+2 : Non-occlusive moderate amount present Tympanic membrane partially obscured (Removal advised)

+3 : Occlusive major amount present Tympanic membrane not visualized (Removal essential)

Abnormalities:
- TM Perforation
- Redness TM
- Retracted TM (Diffused cone of light)
- Foreign Body
- Discharge
- Fungus Growth

4. Tympanometry:

Immittance audiometry screening criteria (ASHA, 1990)*

	Test	>5 yrs old
Pass Criteria	Peak Y PVT TW	0.3-1.4 c.c. 0.6-1.5 c.c. 50-110 daPa

5. Pure Tone Audiometry

Pass criteria : Threshold for 500, 1000, 2000, 4000 Hz <= 25 dBHL

6. Amsterdam Inventory for Auditory Disability and Handicap" (AIADH)

Pass Criteria : Rated no more than 2 questions as 'almost never' and/or 'occasionally'

Appendix B, Questionnaire for evaluating hearing performance

姓名: ______________ 聽覺分析能力問卷調查 Entry No. ____

請以日常生活中遇到的情況回答以下問題, 在適當的 [ ] 內加 [✓]

1 你能否在擠擁的商店中明白店員的說話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

2 當你在街外時，你能否立即聽到汽車從哪個方向駛近？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

3 你能否聽到汽車經過？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

4 你能否以家庭成員的聲線來辨認他們？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

5 你能否辨認出音樂或歌曲中的旋律？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

6 你能否在一個擠擁的聚會中與別人談話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

7 在一個會議中，你能否聽得出別人從演講廳的哪一角發問問題？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

8 你能否容易地在巴士或汽車中與別人對話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

9 當別人在街上叫喚你的名字時，你能否立即望向他／她的正確位置？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

10 你能否分別出汽車和巴士的聲音？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

11 你能否在晚飯時參與少數人的對話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

12 你能否在寧靜的屋內聽到別人從哪個房間的角落跟你對話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

13 你能否分辨到男人和女人的聲線？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

14 你能否聽到音樂或歌曲中的節奏？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

15 你能否在繁忙的街道上與別人對話？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

16 你能否分辨別人聲線的高低音調和變化?

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

17 你能否聽到車子響號聲的來源？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

18 你能否辨認和分別不同的樂器聲？

[ ]從不 [ ]有時／間中 [ ]經常 [ ]幾乎時時

Appendix C, Consent form

Consent Form

Project Title: Cantonese Dichotic Digit Test: Normative findings for Young Adults

Investigator: Tang Heung, Christina (BSc, Speech & Hearing Sciences)

Dr. Bradley McPherson (Project Supervisor)

I, ______________________ (Name), consent to participate in this research project. I have read/understood the information, nature and purpose of this project, and details of the procedure proposed in this study has also been fully explained to me. I have been given the opportunity to ask questions about this study, and they have been answered to my satisfaction. I consent to participate in this study, and understand that I am free to withdraw from the present study at any stage.

______________________	______________________
Researcher's signature (TANG Heung, Christina)	Participant's signature
______________________	______________________
Date	Date

Appendix D, Sequence list for the CDDT

Sequence List For Cantonese Dichotic Digit Test

Test Entry No.					***Stimuli Set Sequence***	***Test Sequence***
1	13	25	37	49	1-2-3	FLR
2	14	26	38	50	1-2-3	FRL
3	15	27	39	51	1-3-2	FLR
4	16	28	40	52	1-3-2	FRL
5	17	29	41	53	2-1-3	FLR
6	18	30	42	54	2-1-3	FRL
7	19	31	43	55	2-3-1	FLR
8	20	32	44	56	2-3-1	FRL
9	21	33	45	57	3-1-2	FLR
10	22	34	46	58	3-1-2	FRL
11	23	35	47	59	3-2-1	FLR
12	24	36	48	60	3-2-1	FRL

Test	
F	Free-recall
L	Directed-left
R	Directed-right

Note:
Odd Entry No. : FLR
Even Entry No.: FRL

Appendix E, Stimuli setting and test instructions in Cantonese and English

STIMULI PRESETATION INTENSITY
60 dB HL

STIMULI USAGE
1. Totally 3 sets of stimuli, each set 20 double digits pairs
2. Randomize the presentation by using the "shuffle" function in the CD player
3. Randomize the stimuli set usage sequence according to the "sequence list"

STIMULI SETTINGS
1. Only 2, 4, 5, 6, 7, 8, 9 are used
2. No repeat digits within the double digit pairs
3. The seven digits used are distributed evenly within and among sets
4. There are no repeated "double digits pairs" among 3 sets
5. 3 double digit pairs for trial for each sub-test (FR. DL, DR)
6 Format of double pairs stimuli in the CD:
3s silence -> Preparation alert -> 1s silence-> 1st digit pair -> 0.5s -> 2nd digit pair -> 2s silence
(inter-trial silence = 5s)

TEST INSTRUCTIONS
Free-recall Test
(English)
You will hear some digits in set of 4 digits. Each ear will hear 2 of them. After hearing to a set of 4 digits, Please tell me all of them. Let's try.
(Trial Stimuli x3). Very good. Let's start.

(Cantonese 中文)
你會聽到一 o 的數目字, 每組有四個數目字, 每邊耳仔會聽到兩個。
聽完一組數目字之後, 請你講哂四個數目字比我聽。
準備好未呀? 我地 o 黎試下先!
-- Trial x3 -- 做得好好, 我地開始咯喎!

Directed-left Test / Directed-right Test
(English)
This time, please only tell me the two digits you heard from the left (right). Raise up your left (right) hand now. Correct. (Incorrect, Raise your left hand now). You could ignore the digits you heard on the other side.
Are you ready? Let's try. -- Trial x3 -- Let's start.

(Cantonese 中文)
今次, 試下講我知左 (右)邊 o 既兩個數目字係乜野。你舉一舉左 (右) 手比我睇下! 係喇, (唔係喎, 再舉一次左手比我睇)。你可以唔理另外果邊耳仔聽到 o 既兩個數目字。準備好未呀? 我地 o 黎試下先!
-- Trial x3 -- 做得好好, 我地開始咯喎!

Appendix F, Case history and record form

CANTONESE DICHOTIC DIGIT TEST RECORD FORM

Entry No.: __________
Test Date: __________

Name : _________________________ D. O. B. : _______________ Age: ________ Sex : F / M

[ ] Mother Tongue: Cantonese / Others Please specify: ___________________

[ ] Medical History

1. **Do you suspect hearing loss?** **[ ] Yes [ ] No**
2. **Do you have cold / illness today?** **[ ] Yes [ ] No**
3. **Have you ever done any surgery before? (Have you ever been to hospital?)**
   [ ] Yes, Please Specify: _________________________ [ ] No
4. **Do you take any medication regularly?**
   [ ] Yes, Please Specify: ____________________________ [ ] No
   ____

[ ] PTA Result (< 25 dB HL)

[ ] 500Hz [ ] 1000Hz [ ] 2000Hz [ ] 4000Hz

[ ] Otoscopy Result

Right Ear

[ ] Ear Wax : 0 / +1 / +2 / +3 (Cerumen Scale)
[ ] Perforation [ ] Retracted TM
[ ] Discharge: fluid / blood
[ ] Redness [ ] Foreign body
[ ] Other abnormalities: _________________

Left Ear

[ ] Ear Wax : 0 / +1 / +2 / +3 (Cerumen Scale)
[ ] Perforation [ ] Retracted TM
[ ] Discharge: fluid / blood
[ ] Redness [ ] Foreign body
[ ] Other abnormalities: ____________

[ ] Tympanometry Result

	Physical Vol. (c.c.)	Peak Y	Tym. Peak Pressure (daPa)	Tym. Width (daPa)	Jerger Type
NORM	**0.6-1.5 c.c.**	**0.3-1.4 c.c.**		**50-110 daPa**	
Right					
Left					

Appendix G, Edinburgh Handedness Inventory

EDINBURGH HANDEDNESS INVENTORY

利手評定方法

		多數會用那一隻手?			間中會用另一隻手嗎?
1	寫字	左	右	左右也可	會 / 不會
2	畫畫	左	右	左右也可	會 / 不會
3	擲東西	左	右	左右也可	會 / 不會
4	刷牙	左	右	左右也可	會 / 不會
5	拿匙羹	左	右	左右也可	會 / 不會

Scoring	
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __

		Which hand do you prefer when:			Do you ever use the other hand?
1	Writing	Left	Right	Either	YES / NO
2	Drawing	Left	Right	Either	YES / NO
3	Throwing	Left	Right	Either	YES / NO
4	Using Toothbrush	Left	Right	Either	YES / NO
5	Using a Spoon	Left	Right	Either	YES / NO

Scoring	
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __
L __ __	R __ __

Marking procedure:

1. Mark the score column according to the following table:

L 2	R	Prefer Left, never use Right
L 1	R	Prefer Left, sometimes use Right
L 1	R 1	Either hand
L	R 1	Prefer Right, sometimes use Left
L	R 2	Prefer Right, never use Left

2. Count the number of X in each column and calculate the total

    Total R Score: ________________

    Total L Score: ________________

    Total R + L Scores: ____________

3. Calculate the laterality quotient:

    Laterality quotient (L. Q.): _______________

    [(R - L) / Total]

    *(Laterality quotients range from **100** (right handed) to **-100** (left handed))*

(> 75: Strong right handers; <75: Strong left-handers; -76-75: Ambidextrous)

Reference:

Oldfield R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 1(9),* 97-113.

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