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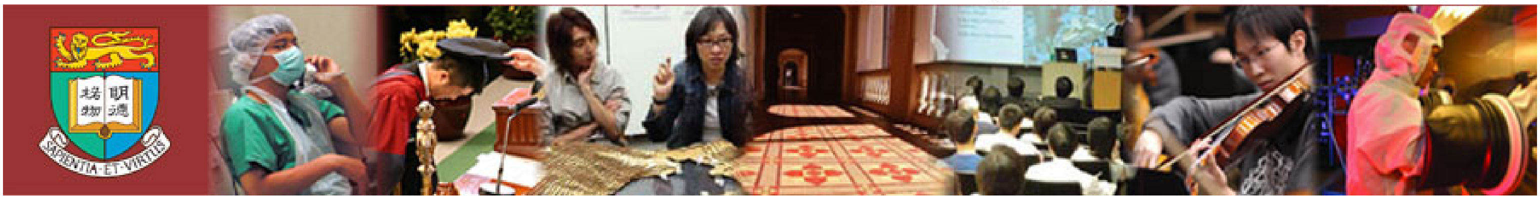

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Norms for the Pitch Pattern Sequence (PPS) Test

for Cantonese Adults

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Norms for the Pitch Pattern Sequence (PPS) Test for Cantonese Adults

TSANG, Ka-Man

Abstract

Normative values for the Pitch Pattern Sequence (PPS) test have not been reported for Chinese populations in the previous literature. Therefore, normative values obtained from 33 Cantonese-speaking normal hearing young adults were developed in this study. The effects of use of two types of response methods (hummed vs verbal responses) and test stimuli (complex vs pure tones) were investigated. When the pure tone stimuli were used, means for percent correct (including reversals) and percent correct (excluding reversals) were 97% and 89% respectively, which were approximately the same as those mentioned in the English adult version of the PPS test instruction manual. The 90th percentile cut-off score was 69% correct (excluding reversals) and 92% correct (including reversals) averaged in both ears using the pure tone stimuli. Significant differences were noted in scores for the hummed and verbal response conditions and separate norms for them were developed. However, an ear difference was found within the complex tone stimuli condition in which the right ear had a significantly higher percentage correct (excluding reversals) than the left ear.

Introduction

Background Information

The American Speech-Language-Hearing Association Task Force on Central Auditory Processing Consensus Development defined a central auditory processing disorder (CAPD) as "an observed deficiency in one or more of a group of mechanisms and processes related to a variety of auditory behaviors " (ASHA, 1996, p.43). This definition is based on a number of behavioral processes.

These processes include: sound localization, auditory discrimination, auditory pattern recognition, temporal aspects of audition (including resolution, masking, integration, and ordering), auditory performance decrements with completing acoustic signals, and the auditory performance decrements with degraded acoustic signals. Therefore, a central auditory test battery should identify auditory processing disorders by addressing these different behavioral processes. The five behavioral auditory test measures include temporal processes, localization and lateralization, low redundancy monaural speech, dichotic stimuli, binaural interaction procedures. However, there are no specific corresponding test measures to the six auditory processes (Schow, Chermak & Berent, 2000).

Literature Review

The development of an auditory processing test battery is not a new topic. There are a number of test batteries available to assess CAPD. The consensus statement recommended a minimal task set for a test battery includes a pure-tone audiometry, word recognition tests, a dichotic task, frequency or duration pattern tests, and temporal gap detection. The temporal processing tasks of frequency or duration tests and temporal gap detection were essential in a test battery. The Pitch Pattern Sequence (PPS) test is a task which requires auditory discrimination, temporal ordering, and pattern recognition. According to a recent survey of auditory processing diagnostic practices (Emanuel, 2002), the PPS test was found to be the most commonly used among the temporal processing tests, such as Duration Pattern Test (Musiek et al, 1990, cited in Emanuel, 2002) in the state of Maryland and various other locations in the United States. It was reported that over 60% of the Internet and Maryland respondents used the PPS test respectively. (Emanuel, 2002). The validity of the frequency pattern test is based upon its sensitivity in identifying patients with known cerebral lesions (Neijenhuis, Stollman, Snik & Van den Broek, 2001).

The PPS test using non-linguistic stimuli is now commercially available from Auditec, Audiology Illustrated, and the Veterans' Administration (Emanuel, 2002). The PPS test from Auditec provides a child version (age 6 to 9) with normative data of means and ranges for three age groups of children. An 'adult' version (age 9 to adult) provides means and ranges for 9 to 10-year-old children and for adults. The Audiology Illustrated frequency pattern test also provided norms for age 8 to 11 and age 12 to adult. It is different from the Auditec test, in that reversals are not counted as normal. In the reversal, the form of the pattern is correct but the sequence is reversed, i.e., "high low high" for "low high low". However, subjects with brain dysfunction were found to have a number of reversals even though it is less frequent for subjects with normal hearing (Musiek, 1994). The inclusion of reversals is a controversial issue.

The response type employed by the test is either hummed or verbal response of "high" or "low" tones in sequence. It was found that both left and right hemispheres and the corpus callosum must interact to give a correct verbal response to tone pattern sequences. Thus, the test would be used with two different types of response methods to identify those people who have dysfunction in either hemisphere or the corpus callosum. Those who have dysfunction in corpus callosum and/or left hemisphere would get better scores using the hummed response method than the verbal one. Those who have dysfunction in the right hemisphere would get better scores using the hummed response method than the verbal one. However, separate norms are not available for the two response methods in the PPS test.

In the present study, the effect of the type of test stimuli used on the performance of perception of temporal sequences was investigated. Apart from the pure tone stimuli that are conventionally used in the PPS test, complex tone stimuli were also used. A pure tone is a simple tone that is sinusoidal. A periodic complex tone is made up of a number of sine waves of different frequencies. Complex tone stimuli provide more "natural" stimuli, more closely linking to the speech signals that CAPD patients experience difficulties in processing. Pitch of a pure tone stimulus is related to its frequency while that of a periodic complex tone is related to its fundamental frequency (Moore, 1989). As the nature of the two tones is different, the mechanisms for pitch perception of them might be different. According to Moore (1989), two theories of pitch perception of pure tones were suggested. One is the place theory. In this theory, two hypotheses were suggested. The first hypothesis is that neurons in the basilar membrane in the inner ear have different distinctive frequencies. Thus, different frequencies of the stimulus would excite different places in the inner ear (Moore, 1989). The second hypothesis is that stimulus would give an excitation pattern in the inner ear. Thus, the pitch of the pure tone stimulus is related to the location of the maximum excitation. Another theory is the temporal theory. It suggests that the tone stimuli would generate a time pattern of nerve impulses that corresponds to the pitch of that stimulus. For the pitch perception of the complex tone stimuli, Moore (1989) also proposed a model. It assumes that a complex tone stimulus would go through a bank of filters. It would then generate activity in neurons of the corresponding center frequencies given through the filers (critical bands). A comparator device would analyze the time intervals of successive nerve impulses at each center frequency. A decision device would then select the most prominent time interval. That would always correspond to the period of the fundamental frequency of the complex tone stimuli. Thus, different mechanisms were suggested for the pitch perception of the two types of tone stimuli. However, there is little information available on that comparison of the performance of the PPS test.

Currently, the PPS test is available only with English instructions. Standardized instructions in Chinese have not yet been developed. Furthermore, no normative studies were done for Chinese populations before. To obtain the normative values of the test for the purpose of clinical practices in the Chinese population become necessary.

Research Objectives

The purpose of this study is to develop simple, standardized instructions and produce norms for the PPS test for Cantonese young adults in Hong Kong.

Research Questions

1.Are the normative data obtained in this study different from the English version of the PPS test (Auditec$_{TM}$)?

2.What are the normative data of the means and ranges of the PPS test using the pure and complex tone test stimuli separately for Cantonese young adults in Hong Kong? Are there any differences between the two types of test stimuli used?

3.What are the normative data of the means and ranges of the PPS test using the hummed and verbal responses separately for Cantonese young adults in Hong Kong? Are there any differences between the two response methods?

4.Are there any differences of the normative data obtained between the right and left ears?

5.Are acoustic reversals (high for low or low for high) common occurrences in normal subjects? What is the percentage of reversals occurred in the total number of errors in normal subjects? Are there any differences between the ears, types of response method, and types of test stimuli used?

Relevance of the Study

As the PPS test is unavailable in a Chinese instruction version, the development of a standardized test instruction and norms for the test will be useful for the clinical assessment of CADP in Chinese adults in Hong Kong.

Method

Subjects

Thirty-four native Cantonese-speaking adults (16 females and 18 males) were recruited. Their age ranged from 19-27, with a mean age of 22. All subjects were naïve listeners with education levels ranging from secondary to tertiary education. They had no history of any hearing disorders, middle ear infections, and no known neurological disorders. All subjects had normal hearing with pure-tone average (0.5, 1, 2, 3 and 4 kHz) less than or equal to 15 dBHL for both ears.

Materials

All tests were conducted in a sound treated room at the audiology center in the Division of Speech and Hearing Sciences at the University of Hong Kong. The pure tone audiometry was conducted using the Madsen Orbiter 922(version 2). The computer-generated PPS test was routed through the clinical audiometer and delivered through the TDH-39 headphones. A microphone was placed in the sound treated room for the subjects to communicate with the researcher outside the room.

Test Stimuli

Two sets of PPS stimuli were developed. One set used pure tones and the other used complex tones. Each frequency pattern using pure tones was composed of three tone bursts which were either a low frequency (L) with 880 Hz or a high frequency (H) with 1430 Hz. They were generated with reference to the English adult version of PPS test ($\text{Auditec}_{\text{TM}}$). In the current investigation, another set of stimuli using complex tones was generated. Each frequency pattern was composed of three tone bursts which were the first seven harmonics of a 220 Hz (a low frequency) and a 357.5 Hz (a high frequency) fundamental frequency (F0). The amplitude of the harmonics followed a –6dB/octave slope. These F0s were chosen because the 4^{th} harmonic frequencies are 880 and 1430 Hz (same frequencies as the pure tones). There were six possible frequency patterns (HHL, LLH, HLH, LHL, LHH, HLL) for the PPS tests and four possible frequency patterns (HL, LL, HH, LH) for the pitch discrimination task which would be administrated before the PPS tests. They were presented in the same order of frequency patterns as those presented in the standard PPS test. The frequency patterns were presented with a tone burst time of 200 ms, a rise/fall time of 10 ms, and an interburst interval of 150 ms. The presentation level was 50 dBHL. The interpattern interval time was not fixed but controlled by the researcher to suit individual subject requirements.

Questionnaire

A questionnaire was constructed with the reference to The Amsterdam Inventory for Auditory disability and Handicap (Kramer, Kapteyn, Festen & Tobi, 1995) was used. Both the English (see Appendix A) and Chinese versions (see Appendix B) of the questionnaires were constructed. The questionnaire consisted of 27 questions. Questions concerned about whether subjects could be able to listen under various daily listening situations. Responses to each question were made by giving a rating, i.e., “almost never”, “occasionally”, “frequently”, and “almost always”. If a subject rates “never” to a question, it means that he/she always has great difficulty in listening under that specific situation. If a subject rates “always” to a question, it means that he/she always has no problem in listening under that situation. The fewer questions are rated as “occasionally” or “almost never”, the less likely the subject has CAPD. Thus, in this study, all the included subjects needed to rate less than 3 questions out of the total 27 questions as either “occasionally” or “almost never”. It indicated that they were very unlikely to have CAPD.

Procedures

Every subject first completed the questionnaire. Both the English and the Chinese version of the questionnaire were given to the subjects. It was followed by pure-tone audiometry to obtain the pure-tone average threshold (PTA) of 0.5, 1, 2, 2.5 and 4 kHz for both ears. Only those subjects who had a PTA threshold less than 15 dB HL were asked to continue the PPS tests. An instruction sheet regarding the procedures of the tests (see Appendix C) was given before the administration of the PPS tests.

Subjects were then required to perform the basic high/low pitch discrimination task for each ear using pure tone stimuli. There were four possible pairs (i.e., HL, LL, HH, LH). They were asked to say “high-low”, “low-low”, “high-high” or “low-high” in response to a pair of tone bursts. PPS tests would only be continued only when the subject was able to perform basic high/low discrimination.

In this study, each subject completed the test with 60 items of frequency pattern for four times using pure and complex tone stimuli with hummed and verbal response for both ears separately. For the “verbal” response, each subject would say “high” and “low” to indicate the frequency pattern sequence, such as “high-low-high”. For the “hummed” response, each subject would hum the frequency pattern sequence. There were four different conditions testing with both ears (see Table 1).

Table 1.

Description of the testing conditions

Condition	Description
A	Pure tone stimuli using hummed response
B	Pure tone stimuli using verbal response
C	Complex tone stimuli using hummed response
D	Complex tone stimuli using verbal response

Balancing using random starting order with rotation was used. All subjects were randomly assigned to one of the orders (i.e., ABCD, BCDA, CDAB, DABC). Half of the subjects started with the testing of the left ear and another half started with the right ear during each testing condition. There was a 5-minute break in between each testing condition. The whole session took about 90 minutes including the breaks. No feedback on the performance of the tests was provided.

Test-Retest Experiment

Four male and four female subjects were retested after 2 weeks to estimate the test-retest reliability of the modified PPS test.

Results

Data Analysis of the PPS Test

In each testing condition, the first 10 test items for each ear were practice items. Scores were based on 50 test items only. Percent correct (including reversals), percent correct (excluding reversals) for each ear using two types of test stimuli with two types of response method constituted the scores. In the present study, percent reversals and percent reversals/total errors were also investigated. It was noted that one subject, who passed the selection criteria for the PTA and the questionnaire, made all responses as reversals in the verbal response conditions. The possible reason might be due to his poor ability to identify the "high" or "low" pitch verbally even though he was able to tell the difference between them. This was an extreme case that might not be representative in the normal population. Thus, those results were not included in the final analyses. Descriptive statistical measures were computed for 33 subjects only. Details of their pure tone thresholds were given in Table 2.

Table 2.
Pure tone thresholds (in dB HL) of all 33 subjects

Ear		Frequency (Hz) 500	1000	2000	3000	4000
Left						
	Mean	11.67	9.39	10.30	8.79	9.24
	S.D.	6.57	4.80	4.67	5.59	5.88
Right						
	Mean	11.67	9.24	8.78	9.24	8.48
	S.D.	5.95	5.17	4.51	5.88	5.37

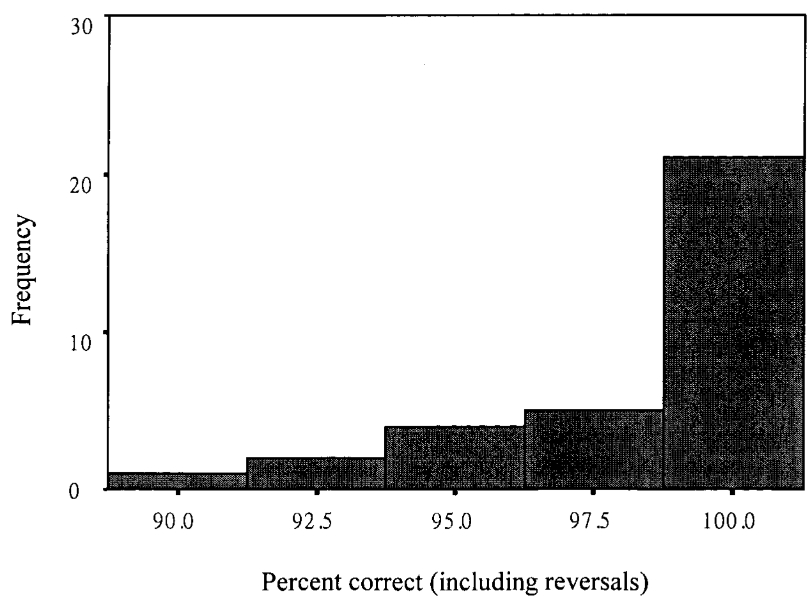

Figure 1. Frequency distribution of the scores in verbal response condition using complex tone stimuli in the right ear.

The distributions of the scores were examined. According to the Shapiro-Wilks Test the scores in all of the testing conditions did not follow a normal distribution (p=0.01). Due to the skewed distributions of the scores (an example of frequency distribution was shown in Figure

1), non-parametric tests were therefore used for the analysis of differences in means scores of percent correct (including reversals), percent correct (excluding reversals), percent reversals in different testing conditions.

Descriptive Statistics for the Data of the PPS Test

Descriptive statistical measures were computed and shown in Table 3 and Table 4. According to Table 3, ceiling effect was showed in all the conditions using hummed responses. Thus, analysis was focused on the verbal response condition. From Table 4, it was noted the scores obtained in both ears were approximately the same when the pure tone stimuli were used. However, more reversals were showed in the left ear condition. Also, a higher percentage of correct (excluding reversals) were showed in the right ear when the complex stimuli were used.

Table 3.
Means and standard deviation (S.D.) of the scores in the hummed response condition.

	Complex tone			Pure tone		
	Correct (including reversals)	Correct (excluding reversals)	Reversals	Correct (including reversals)	Correct (excluding reversals)	Reversals
Left ear						
Mean	99.94	99.94	0.00	99.76	99.76	0.00
SD	0.35	0.35	0.00	0.83	0.83	0.00
Right ear						
mean	99.76	99.76	0.00	99.64	99.64	0.00
SD	1.09	1.09	0.00	1.17	1.17	0.00

Table 4.
Means and standard deviation (S.D.) of the scores in the verbal response condition.

	Complex tone			Pure tone		
	Correct (including reversals)	Correct (excluding reversals)	Reversals	Correct (including reversals)	Correct (excluding reversals)	Reversals
Left ear						
Mean	97.94	87.76	10.18	96.61	89.45	7.15
SD	3.55	16.23	14.72	6.72	13.10	9.89
Right ear						
Mean	98.36	91.27	7.09	96.85	88.91	7.94
SD	2.76	11.51	10.62	6.06	14.97	10.37

The 90th percentile cut-off points were determined within the verbal response conditions. In the pure tone condition, 90% of the scores were 69% correct or higher (excluding reversals) and 92% correct or higher (including reversals) averaged in both ears. In the complex tone condition, 90% of the scores were 92% correct or higher (excluding reversals) and 70% correct or higher (including reversals) averaged in both ears.

It was also found that the percentage of reversals making up of the total errors in all the 33 subjects was about 67% and 82% averaged in both ears for the pure and complex tone conditions respectively. (see Figure 2). They were calculated by dividing total number of reversals by total number of errors made in all 33 subjects.

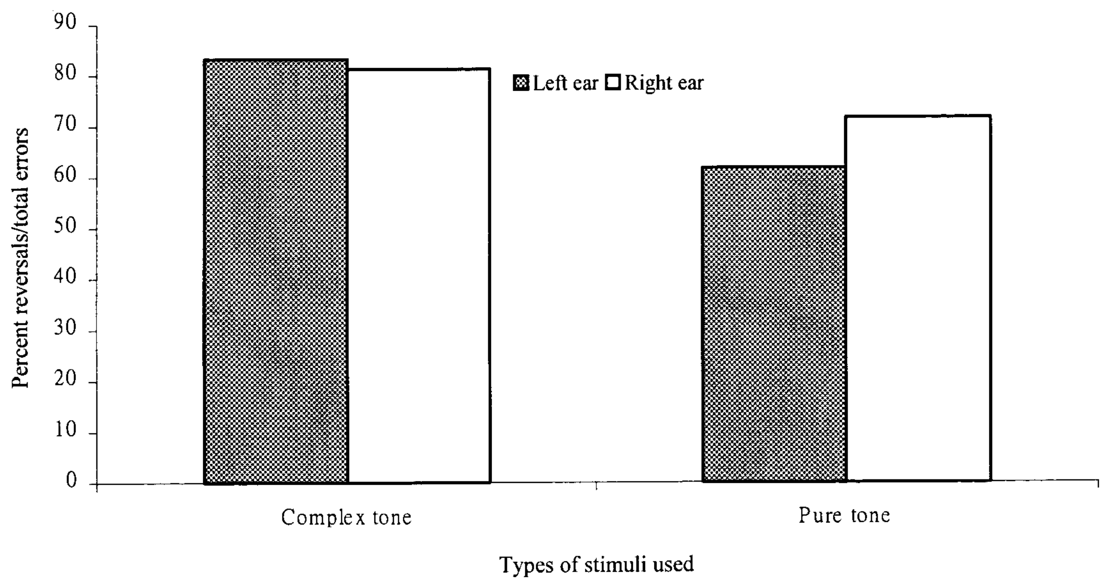

Figure 2. Ratio of acoustic reversals to total errors in all 33 subjects.

Relationship Between the Pitch Discrimination Task and the PPS Test

Correlation rank coefficients (Spearman's Rho, $p<0.01$,two tailed) for the scores of percent correct (excluding reversals) obtained between the pitch discrimination task and the PPS tests using verbal response were examined. Significant correlations were showed between the pitch discrimination task and the PPS test for both types of stimuli tested with each ear (i.e., pitch discrimination task and the PPS test tested with complex tone stimuli for the left ear, $r=0.55, p<0.001$; pitch discrimination task and the PPS test tested with complex tone stimuli for the right ear, $r=0.63, p<0.001$; pitch discrimination task and the PPS test tested with pure tone stimuli for the left ear, $r=0.64, p<0.001$; pitch discrimination task and the PPS test tested with pure tone stimuli for the right ear, $r=0.61, p<0.001$).

As the pitch discrimination task was performed using verbal response, correlation analysis was performed only for the verbal response condition.

Differences Between Different Response Conditions

Wilcoxon's matched pairs test was performed to compare the means between the verbal and hummed response conditions. The percent correct (excluding reversals) for the hummed response were significantly higher than the verbal one in all testing conditions (i.e., left ear/complex tones, $T=1$, $p=0.000$; right/complex tones, $T=1$, $p=0.000$; left ear/pure tones, $T=0$, $p=0.000$, right ear/pure tones, $T=0$, $p=0.000$).

Differences Between the Ears and Types Of Stimuli Used

Wilcoxon's matched pairs test was used to statistically examine the differences in mean percent correct (including reversals), percent correct (excluding reversals), and reversals.

In the complex tone stimuli condition, the mean score of percent correct (excluding reversals) in the right ear was significantly higher than that of the left ear ($T=7, p=0.003$). Also, the mean percent reversals in the left ear were significantly higher than that in the right ear ($T=8$, $p=0.011$). However, mean percent correct (including reversals) showed no significant difference between left and right ear ($T=6, p>0.05$). In the pure tone stimuli condition, there were no significant differences in any of the scores measured between the left and right ear.

Comparing the scores between the complex and pure tone stimuli within left and right ears, the percent correct (excluding reversals) in the complex tone condition was significantly than that in the pure one within the right ear ($T=10$, $p=0.032$). There was a greater percentage of reversals made in the left ear within the complex tone stimuli condition than the pure one. However, this difference was not statistically significant. ($p>0.05$).

As shown in Figure 2, there were consistent proportions of acoustic reversals to total errors across the ear within each stimuli condition. It was found that higher proportion of reversals to errors was found in the complex tone stimuli condition than the pure one.

Test-Retest Reliability

Test and re-test scores were obtained by eight subjects (four males and four females). Wilcoxon matched pair test was performed to compare the mean scores between the test and re-test conditions. For the hummed responses, since all subjects got 100% correct (excluding reversals) without making any reversals, there were obviously no differences between the test and re-test conditions. For the verbal responses, no significant differences were noted in mean percent correct (including reversals), percent correct (excluding reversals) and reversals between the test and re-test conditions ($p>0.05$).

Data Analysis of the Questionnaire

Questions developed by Kramer et al (1995) concerned with five basic auditory abilities (i.e., intelligibility in quiet, intelligibility in noise, distinction of sounds, detection of sounds, and auditory localization) were modified for screening of normal subjects in this study. All subjects rated less than 3 questions as either "occasionally" or "almost never". Fourteen subjects gave all the answers with either "frequently" or "almost always". Eight subjects gave 1 out of 27 answer with "occasionally". Seven subjects gave 2 out of 27 answers with "occasionally". Four subjects gave 3 out of 27 answers with "occasionally". None of the subjects gave any answer with "almost never". This indicated that none of the subjects reported any significant difficulty in daily listening situations.

Discussion

The purpose of this study was to obtain the normative values of the PPS test for Cantonese young adults in Hong Kong. The means and ranges of the scores using the pure tone test stimuli with verbal response obtained in this study were compared with those obtained in the English adult version of the PPS test ($Auditec_{TM}$). The mean percent correct (including reversals) of the present data was approximately the same as that shown in the Auditec test instruction manual (Auditec, n.d.) (97% versus 96%). In comparing the mean percent correct (excluding reversals) of this study with the English one, similar result (89% versus 90%) but a wider range (44-100% versus 88-100%) was shown. The reason for this difference is unclear. Generally, the norms obtained in this study were in agreement with those shown in the English one.

Musiek (1994) found that the 90^{th} percentile cut-off score was 78% correct (excluding reversals) using pure tone stimuli. When we used this criterion in the present data, five subjects (15%) failed the test. This suggested that our result is different from those reported by Musiek (1994). In the present study, lower cut-off score, which was 68% correct (excluding reversals) averaged in both ear using pure tone stimuli, was found. This indicated that 90% of scores were 68% correct or better. This value should be used as the cut-off criteria for a normal Cantonese-speaking young adult population. It is unclear why lower cut-off point was found. One possible reason for the difference is that relatively less subjects was used in this study. The result of this study was also compared with those reported by Neigenhuis et. al. (2001). They found higher cut-off scores than the present study (89% vs 68% correct). Such difference might be caused by different number of test items used. Thirty rather than sixty items were presented in each ear in their study (Neigenhuis et. al., 2001).

Scores obtained in hummed and verbal response conditions were compared. In the hummed response condition, a ceiling effect was shown. No acoustic reversal was made in any of the subjects. Mean correct response was about 100% and the range of scores was 94% to 100%. Norms for hummed response condition were different from those obtained in verbal one. Most subjects reported that it was easier to hum the pattern sequences than label them verbally. This could be explained by different mechanisms involved in the two types of responses. In a verbal response, it requires the interhemispheric transfer through the corpus callosum from the right hemisphere for decoding acoustic contour to the left hemisphere for temporal ordering and verbal labeling (Bellis & Ferre, 1999; Emanuel, 2002). However, when subjects hum the pattern sequences, transfer of acoustic information interhemispherically is unlikely to be involved. This was also supported by the study done by Musiek et al. (1980; cited in Emanuel, 2002). They found that split-brain patients could hum the sequence patterns normally but failed to report them verbally. Now, two separate norms for the two response conditions were developed. If the subject has poor scores in hummed response condition, problems in the right hemisphere may be evaluated. If the subject can hum the pattern sequences but fails to verbalize them correctly, the corpus callosum and/or the left hemisphere may be involved but cannot be evaluated with this test individually (Chermak & Musiek, 1997). Other tests will also be needed. Comparison of the scores in the two response conditions could therefore indicate the integrity of the hemispheres (Bellis & Ferre, 1999).

In the Auditec test instruction manual (Auditec, n.d.), it mentioned that there is no significant difference in response methods. However, in this study, normal subjects showed significant higher scores in hummed than verbal response condition. More reversals and wrong responses were made in verbal response condition. Interestingly, some of the subjects reported that they needed to hum the pattern sequences silently in their mind before labeling them verbally. More time might be needed to process the acoustic information before they could give verbal responses. At a few instance, they would forget the pattern they just listened to, so they would give responses by guessing. Jirsa (2001) found that children with auditory processing disorders also had relatively higher scores in the hummed response condition than the verbal one but had lower scores in both response conditions when compared to the normal subjects.

It was found that normative values for percent correct (including reversals) and percent reversals obtained in complex tone stimuli condition were approximately the same as those in pure one. There was no significant difference in those scores. However, significant higher percent correct (excluding reversals) in the complex tone stimuli condition than the pure one within the right ear. This indicates that the performance of the test in the right ear might be different when different types of stimuli are used.

When we looked at the ear difference in scores with verbal response in the two stimuli conditions, it was showed that there were significantly higher mean percent correct (excluding reversals) in right ear in the complex tone stimuli condition. At the same time, a significant higher percentage of reversals were made in the left ear. However, no ear effect was shown in pure tone stimuli condition. Other studies in the literature also found that there was no significant ear difference when pure tone test stimuli were used (Pinheiro & Godbey, 1973, cited in Musiek, 1994). Some other studies found right ear would make more pattern reversals than the left ear, which were contradictory to the findings in this study. Ptacek and Pinheiro (1970) reported that more reversals for noise-burst patterns based on intensity differences were made in the left ear. McRoberts and Sanders (1992) found left-ear advantage on the dichotic fundamental-frequency contour tests. This indicated that there might be a left-ear advantage for acoustic processing. However, it was difficult to compare our results with them as the methodology used was different. There is no literature on investigation of the use of complex tone test stimuli in the PPS test. The reason for such ear differences is unclear unless further investigation is carried out.

When we looked at the occurrence of acoustic reversals in this study, it showed that acoustic reversals were common errors in normal subjects. Those reversals made up about 67% of total errors in pure tone stimuli condition. This is inconsistent with the range (30% to 60%) mentioned in the Auditec test instruction manual (Auditec, n.d.). A higher value was obtained. In the present investigation, we also found that reversals made up of about 82% of total errors when complex tone stimuli were used, which was greater than that of pure tones. Although the mean percent reversals averaged in both ears obtained in the two tone stimuli conditions were similar, higher proportion of reversals to total errors were found in the complex tone stimuli condition than in the pure one. More errors in overall were made when pure tone stimuli was used

The explanation of the acoustic reversals for the pitch pattern sequences was still not yet clear. There is limited information available in the literature focused on the investigation of occurrence of pattern reversals in normal population. Ptacek and Pinheiro (1970) studied the perception of pattern sequences based on intensity differences in normal population. They also found that a large proportion of errors were pattern reversals. In this study, it was observed that most subjects could notice that they had made a reversal immediately after they just labeled the pattern sequence verbally during the test. Short-term memory might be a cause (Ptacek & Pinheiro, 1970). Interestingly, several subjects, who made relatively more reversals in the test, commented that they had difficulties in labeling the tones. They reported that they sometimes confused whether a high pitch tone should be labeled as "high" or "low" pitch and the vice verse. Although they could hum the pattern sequences correctly, they may be confused and label the pattern sequences as reversals consequently. On the other hand, it was suggested that those reversals might have some physiological mechanism similar to the acoustic confusions which had been investigated by previous studies (Ptacek & Pinheiro, 1970). In their studies, confusions were the errors which often had one element identical in the same position or two identical elements in reversed position as in the sequence of meaningful stimuli presented, i.e., digits and letter names (the Conrad studies and Wickelgren studies, cited in Ptacek & Pinheiro, 1970). As we found that no reversals were made in all of the subjects when a hummed response was used, the occurrence of reversals might attribute to the interhemispheric transfer and/or the left hemisphere. However, the exact neural mechanism for reversals was still unknown without further research.

There is limited literature on comparison of the number of reversals made in the PPS test between normal subjects and those with brain abnormalities. Musiek (1994) noted that people with normal hearing would make a small number of reversals but patients with brain damages would make a large number of reversals in the PPS test. So, reversals should be considered as incorrect responses. Currently, the Auditec test instruction considers reversals as correct but scores them separately while another commercially available test, the Audiology Illustrated frequency pattern test instruction scores them as incorrect. In the present study, a certain percentage of reversals also occurred in normal subjects. Further investigation on the PPS test in the patients with brain abnormalities might be needed in order to find out if the reversals responses were different from those normal subjects.

Correlational analysis between preliminary pitch discrimination task and the PPS test was performed. It is obvious that pattern recognition of three-tone-burst sequences is more difficult than tone burst pairs discrimination task (Pinheiro & Ptacek , 1971). At present, in the Auditec test, the pitch discrimination task is used for ensure the listeners could be able to discriminate high from low pitch. However, the passing criterion for the pitch discrimination task in the Auditec test is not clearly mentioned in the instruction manual. Reversals should not be scored as incorrect responses in that part as they are not in the PPS test. In the present study, most errors found in that task were reversals, no incorrect responses (excluding reversals) which showed inability to tell the differences within the tone pairs (e.g. labeling tone pairs of "high-low" as "low-low") were found in most of the subjects. It was noted that normal subjects who made many reversals in the discrimination task, would also make relatively more in the PPS test. The pitch discrimination task was found to be significantly correlated with the PPS test. Therefore, discrimination ability of basic high/low tone pairs might be a prerequisite in the PPS test.

The test and re-test evaluation indicated that there was no significant difference between the results in the PPS test before and after a period of 2 weeks.

The PPS test is often included in a central auditory processing test battery. It can assist in the diagnosis of CAPD and provide information concerning CAPD management. Performance in this test could give insights about several central auditory processes, such as contour recognition, interhemispheric transfer and linguistic labeling (Musiek & Chermak, 1995). Generally, intervention approaches would focus on enhancing language resources, improving the listening environment and enhancing the signal quality (ASHA, 1996).

Now, norms of the PPS test for Cantonese-speaking young adults have been developed. The present study did not examine the relationship between the constructed Chinese version of The Amsterdam Inventory for Auditory Disability and Handicap (Kramer, Kapteyn, Festen & Tobi, 1995) and the subject performance in the PPS test. All normal subjects included were reported to have good hearing ability in various daily listening situations. The questionnaire was only used as a screening tool to assure normal hearing ability in this study's subjects. Thus, how normal subjects with relatively poor hearing in daily situations as indicated in the questionnaires would perform in the PPS test, such as number of reversals made, is unknown without further investigation is carried out.

Experiments on the population with CAPDs and the population with children who have learning difficulties and normal peripheral hearing, might be needed to ascertain how their performances in the PPS test would be different from the normal populations. On the other hand, larger sample size could also be used in future investigations on the differences of the reversals made between the complex and pure tone stimuli conditions.

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Appendix A

The English version of The Amsterdam Inventory for Auditory Disability and Handicap

Questionnaire

Name: ___________ Age/Sex: ___________ Contact number: ________________

Please answer the following questions according to your daily experience

1 Can you understand a shop assistant in a crowded shop?

__Almost never __Occasionally __frequently __almost always

2 Can u carry on a conversation with someone in a quiet room?

__Almost never __Occasionally __frequently __almost always

3 Do you immediately hear from what direction a car is approaching when you are outside?

__Almost never __Occasionally __frequently __almost always

4 Can you hear cars passing by?

__Almost never __Occasionally __frequently __almost always

5 Do you recognize members of your family members of your family voices?

__Almost never __Occasionally __frequently __almost always

6 Can you recognize melodies in music or songs?

__Almost never __Occasionally __frequently __almost always

7 Can you carry on a conversation with someone during a crowded meeting?

__Almost never __Occasionally __frequently __almost always

8 Can you carry on a telephone conversation in a quite room?

__Almost never __Occasionally __frequently __almost always

9 Can you hear from what corner of a lecture room someone is asking a question during a meeting?

__Almost never __Occasionally __frequently __almost always

10 Can you hear somebody approaching from behind?

__Almost never __Occasionally __frequently __almost always

11 Do you recognize a presenter on TV by his/her voice?

__Almost never __Occasionally __frequently __almost always

12 Can you understand text that's being sung?

__Almost never __Occasionally __frequently __almost always

13 Can you easily carry a conversation with somebody in a bus or car?

__Almost never __Occasionally __frequently __almost always

14 Can you understand the presenter of the news on TV?

__Almost never __Occasionally __frequently __almost always

15 So you immediately look in the right direction when somebody calls you in the street?

__Almost never __Occasionally __frequently __almost always

16 Can you hear noises in the household, like running water, vacuuming, a washing machine?

__Almost never __Occasionally __frequently __almost always

17 Can you discriminate the sound of a car and a bus?

__Almost never __Occasionally __frequently __almost always

18 Can you follow a conversation between a few people during dinner?

__Almost never __Occasionally __frequently __almost always

19 Can you understand the presenter of the news on the radio?

__Almost never __Occasionally __frequently __almost always

20 Can you hear from what corner of a room someone is talking to you being in a quiet house?

__Almost never __Occasionally __frequently __almost always

21 Can you hear the door-bell at home?

__Almost never __Occasionally __frequently __almost always

22 Can you distinguish between male and female voices?

__Almost never __Occasionally __frequently __almost always

23 Can you hear rhythm in music or songs?

__Almost never __Occasionally __frequently __almost always

24 Can you carry on a conversation with someone in a busy street?

__Almost never __Occasionally __frequently __almost always

25 Can you distinguish intonations and voice inflections in people's voices?

__Almost never __Occasionally __frequently __almost always

26 Do you hear from what direction a car horn is coming?

__Almost never __Occasionally __frequently __almost always

27 Can you recognize and distinguish different musical instruments?

__Almost never __Occasionally __frequently __almost always

Appendix B

The Chinese version of The Amsterdam Inventory for Auditory Disability and Handicap.

問卷

姓名: ______________ 年齡/性別: ______________ 聯絡電話:___________

請以**日常生活**中遇到的情況回答以下問題。

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. 你能否在一間寧靜的房間與別人對話？

__從不 __有時／間中 __經常 __幾乎時時

3. 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

4. 你能否聽到汽車經過？

__從不 __有時／間中 __經常 __幾乎時時

5. 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

6. 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

7. 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

8. 你能否在一間寧靜的房間與別人在電話中對話？

__從不 __有時／間中 __經常 __幾乎時時

9. 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

10. 你能否聽到別人從你背後接近你?

__從不 __有時／間中 __經常 __幾乎時時

11. 你能否以電視節目主持人的聲線來辨認他／她？

__從不 __有時／間中 __經常 __幾乎時時

12. 你能否明白歌曲中的內容？

__從不 __有時／間中 __經常 __幾乎時時

13. 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

14. 你能否明白電台的新聞報導員報道新聞？

__從不　　__有時／間中　　__經常　　__幾乎時時

15. 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

16. 你能否在家裡聽嘈雜聲，例如開水聲、吸塵聲和洗衣機聲？

__從不　　__有時／間中　　__經常　　__幾乎時時

17. 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

18. 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

19. 你能否明白電視上新聞報道員報道新聞？

__從不　　__有時／間中　　__經常　　__幾乎時時

20. 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

21. 你能否聽到家裡的門鐘響？

__從不　　__有時／間中　　__經常　　__幾乎時時

22. 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

23. 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

24. 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

25. 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

26. 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

27. 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.

Instruction sheet regarding the procedures of the tests

Instructions 指引

General information:

簡介資料

The purpose of this study is to develop norms for the Pitch Pattern Sequence (PPS) Test for Cantonese-speaking young adults in Hong Kong.

是次研究之目的是發展音調花樣序列測驗之常模數據；是次研究對象是操廣東話之香港成年人。

The PPS test is used for the purpose of assisting in the assessment of central auditory processing disorders. This (PPS) test is made up of a series of three tone burst patterns. The test will begin with a check session. It contains 20 tone pairs which are used to make certain that you can tell the difference between HIGH and LOW pitch. It will be followed by two sets of 60 three tone patterns, 60 for each ear.

音調花樣序列測驗是爲了協助檢驗「中樞性聽覺神經紊亂」而設計的。本測驗含一系列以三個短純音組成的排列。受測者首先需聆聽二十對短純音,以確定受測者者能分辨高音頻與低音頻。這檢查部份完成以後，包含兩套而每套六十組以三個短純音組成的排列，分別於兩耳給聲。

Procedures 程序:

1. Pure tone audiometry

   純音聽力檢查

   You will hear "bip" sounds with different frequency and loudness. You will be asked to raise up your hand when you hear a "bip" sound. This test will be presented to both ears separately. It will takes around 5-10 mins.

你將會聽到一連串高音或低音、大聲或小聲的「嗶嗶」聲,先在一耳，然後另一耳。當你每一次聽到聲音，就請你舉手表示聽到；當聲音停止後,請立即放下手來。這個檢查需時五至十分鐘。

Only subjects who have normal hearing for both ears will be asked to perform the following test.

若你的聽覺能力正常,你將會繼續以下測驗。

2. Pitch Pattern Sequence Test

音調花樣序列測驗

The test will begin with a check session. It contains 20 tone pairs which are used to make certain that you can tell the difference between HIGH and LOW pitch. It will be followed by two sets of 60 three tone patterns, 60 for each ear.

首先你會分別以左耳和右耳聽到二十對短純音,以確定你能分辨高音頻與低音頻。然後, 你會分別以左耳和右耳聆聽六十組以三個短純音組成的排列。

When you hear a set of tone burst pattern, you will be asked to say HIGH and LOW or hum the tone patterns indicating your perception of the tone patterns.

測驗期間,當你聽到一組的刺激音,你需要立即讀出「高」和「低」或哼出音調次序來表示出你所聽到的音調排列次序。測試員將指示你用何種對刺激音反應的方式。

The test will be performed four times. It will take around 20 minutes for each time. 5 minutes break will be given in between each time. The whole session will take about 2 hours.

這個測驗將重覆進行四次。每次需時約二十分鐘, 期間將有約五分鐘的休息。整個過程需時二小時。

Thanks for your cooperation and participation!

多謝你的合作和參與!

Appendix D

The Chinese translation of the Auditec test instruction for administration

音調花樣序列測驗 (Pitch Pattern Sequence Test)

音調花樣序列檢查是爲了協助檢驗「中樞性聽覺神經紊亂」(central auditory processing disorders)而設計的。本測驗能用於腦病變和有學習困難的病人作診斷用途。本測驗含一系列以三個短純音組成的排列。變數是頻率或音調。測驗的第一部份是頻率高低認知的能力檢查。這部份包含多對短純音，用以確定受測者能夠分辨高音和低音的。這檢查部份完成以後，包含兩套而每套六十組以三個短純音組成的排列，分別於雙耳給聲。然而，首十組排列只是用來作練習用途，而將不會給分數的。

受測者將給予足夠數目的短純音排列，來確定受測者能夠分辨高音和低音。對於正常人來說，這檢查部份是十分容易的。但無論如何，受測者必須能分辨高低音頻，才能繼續進行本測驗。

一套六十組的排列將於每一耳給聲。首十組只作練習聆聽用途，不會給予分數的。因此，計算分數時，只會計算於每耳 50 組排列所得的分數。每組短純音將以受測者 1000 Hz 聽覺閾值上 50 dBSL 分別於雙耳給聲。

測試員會示乎情況和測驗配套而指示受測者用其中一種反應方式表達所聽到的音調排列。

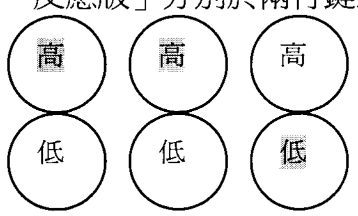
通常受測者將以口頭或鼻哼方式表達音頻高低次序。

「口述」反應有以下四種方法：

(一). 用文字寫出「高」來表示高音；「低」表示低音。

(二). 用口頭說出「高」或「低」來表示音頻的排列次序。

(三). 用「反應版」分別於兩行鍵上，按「高」或「低」來表示音頻的排列次序。



(四). 受測者將給六塊柱體積木，三塊是高柱，另外三塊是矮柱。

受測者需用手指出「高」或「低」柱來表示音頻的排列次序。

若受測者使用「鼻哼」反應方式表示音頻的排列次序時，測試員應先檢查其「哼聲」的表達能力。

計分方法：

分數將以正確率計算出來。聲調顛倒會分別計算，但亦需計算於正確率之內。

聲調顛倒：

顛倒(即「高」變成爲「低」，「低」變成爲「高」) 。在普遍的正常人中，「顛倒」通常

佔錯誤排列中的 30 至 60%。「顛倒」是指音頻高低的排列次序顛倒，但音頻的次序排列形式是正確的。這即是表示「高音」轉爲「低音」，以及「低音」轉爲「高音」。
記憶力短暫可能會是顛倒排列的原因。

正確排列	顛倒排列
高低高	低高低
高高低	低低高
高低低	低高高
低高低	高低高
低低高	高高低
低高高	高低低

測驗分析：
比較「哼聲」與「口述」或「手動」的反應方式時，有些病人能準確地「哼」出音調的排列次序，但當用「口述」或「手動」反應方式時，測驗表現會較差。這能有助於診斷某些腦病變和學習障礙。
用「哼聲」反應是需要比較少的處理和分析，然而，「手動」和「口述」反應方式是需要將聽覺輸入轉爲較複雜的輸出，這涉及專注的思考和語言處理的傳送。雖然，雙側腦顯然地會負責處理排列的次序，但在大多數病人之中，「手動」或「口述」反應方式是通過腦半球傳送訊息的。例如，腦裂 (split brain) 的病人對於次序的排序會較易，但就不能夠以「口述」或「手動」的反應方式表達出來。
而有很多有學習障礙的兒童都會有以上相似的表現。

在腦顳(temporal lobe area)或腦顳頂間部份 (temporo-parietal area) 有病變的人，雙耳的表現都會差的。然而，在右腦側病變的人中，左耳(與病變位置對側)的得分會較高的。
而單側腦病變亦使「口述」、「手動」和「哼聲」反應的表現降低。
若病變位置是位於或於上橄欖體 (superior olivary complex) 的上面，病變會使與病變位置對側的耳朵所獲得的分數降低。

對於正常人來說，無論用任何一種反應方式以及耳朵，測驗所得分數是沒有太大分別的，而分數會是高於 88%的。