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# Behavioural indices of central auditory processing

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**Defence R&D Canada**  
Technical Memorandum  
DRDC Toronto TM 2009-026  
June 2009

Canada



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## Abstract

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This research examined the effect of aging, gender, ear and practice on the outcomes of a battery of behavioural tests used in clinical practice to diagnose pathology of the central auditory system. The test battery included the Dichotic Digits Test, Duration Patterns Test, Frequency Patterns Test and Gaps-in-Noise Test. The ultimate goal was to determine whether such tests might be useful in diagnosing pathology of central origin in cases where peripheral auditory pathology has been ruled out but hearing problems persist. Two groups of 12 subjects aged 18-39 years and 40-60 years, respectively, were tested. Half of each group were males and half females. All were fluent in English, had normal or corrected normal vision and normal hearing, and had no history of otological or neurological disease or head trauma. Subjects were tested individually in a sound proof booth. The test materials were commercially available on compact discs (CDs). These were presented at a comfortable listening level. All but the Gaps-in-Noise Test were presented twice. Subjects recorded their responses using paper and pencil. The results showed that there were no significant effects of age, gender, ear or replication. Thus, the outcomes for the 24 subjects were pooled. Means and standard deviations were similar to published norms. However, based on the high incidence (25%) of subjects whose scores would have been judged abnormal and the relatively wide range of outcomes for the Duration Patterns Test, and the published low hit rate for individuals with central auditory nervous system pathology for the Gaps-in-Noise Test, these two tests were not recommended for further consideration.

## Résumé

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Cette recherche portait sur l'effet du vieillissement, du sexe, de l'oreille et de la pratique sur les résultats d'une batterie de tests comportementaux utilisés en clinique pour le diagnostic des troubles du système auditif central. La batterie comprenait le test d'écoute dichotique (de chiffres), le test des patrons de durée, le test des patrons de fréquence et le test de détection du silence. En dernière analyse, il s'agissait de déterminer si ces tests pouvaient être utiles pour le diagnostic d'un trouble auditif central dans les cas où a écarté la possibilité d'un trouble auditif périphérique mais où des problèmes d'audition persistent. Deux groupes de 12 sujets âgés de 18 à 39 ans et de 40 à 60 ans, respectivement, ont passé les tests. La moitié des membres de chaque groupe étaient de sexe masculin, l'autre, de sexe féminin. Tous parlaient couramment l'anglais, avaient une vision normale, avec ou sans correction, et une audition normale. Ils n'avaient en outre aucun antécédent de pathologie de l'oreille, de trouble neurologique ou de traumatisme crânien. Les sujets ont été testés individuellement dans une cabine insonorisée. Il s'agissait de tests offerts sur le marché sur disque compact (CD), diffusés à un niveau d'écoute confortable. Tous les tests, sauf le test de détection du silence, ont été présentés deux fois. Les sujets ont noté leurs réponses à la main (crayon-papier). Il ressort de l'expérience que l'âge, le sexe, l'oreille et la répétition n'avaient aucun effet significatif sur les résultats. Aussi, les résultats des 24 sujets ont été mis en commun. Les moyennes et les écarts types étaient comparables aux normes publiées. Toutefois, étant donné l'incidence élevée (25 %) de sujets dont le score aurait été jugé anormal et l'intervalle relativement vaste des scores obtenus au test des patrons de durée, et vu le taux de réussite publié relativement faible au test de détection du silence des sujets présentant un trouble du système nerveux auditif central, il n'est pas recommandé d'envisager de recourir à ces deux tests.

# Executive summary

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## Behavioural indices of central auditory processing

**Sharon M. Abel; Dan van der Werf; DRDC Toronto TM 2009-026; Defence R&D Canada – Toronto.**

**Introduction:** Audiologists administer non invasive tests to determine the location and extent of peripheral auditory pathology which may be of middle ear, cochlear or eighth nerve origin. These tests generally include the measurement of air and bone conduction thresholds, speech reception threshold, speech discrimination, and tympanometry. Measurement of the auditory brainstem response (ABR) or otoacoustic emissions (OAEs) may be included if a brainstem lesion is suspected, although neither can detect high brainstem or cortical involvement. Recent studies have suggested that various psychoacoustic tests, viz., the Dichotic Digits Test, Duration Patterns Test, Frequency Patterns Test and Gaps-in-Noise Test can differentiate between peripheral and central auditory pathology. The present research examined the effect of aging, gender, ear and practice on the outcomes of these tests and compared the results to published norms for young adults. The ultimate goal was to determine whether such tests might be useful for diagnosing pathology of central origin in cases where peripheral auditory pathology has been ruled out but hearing problems persist. Two groups of 12 subjects, half male and half female, aged 18-39 years and 40-60 years, respectively, were tested. All were fluent in English, had normal or corrected normal vision and normal hearing, and had no history of otological or neurological disease or head trauma. Subjects were tested individually in a sound proof booth. The test materials were presented monaurally or binaurally over a headset at a comfortable listening level. All but the Gaps-in-Noise Test were presented twice. Responses were recorded on answer forms.

**Results:** There was no effect of age, gender, ear or replication. Thus, the data were averaged for ear and replication within subject and the results for the four groups pooled. Means and standard deviations were in good agreement with published values for young adults. However, based on the high incidence of subjects (25%) in the present study whose scores would have been judged abnormal and the relatively wide range of outcomes for the Duration Patterns Test, and the published low hit rate for individuals with central auditory nervous system pathology for the Gaps-in-Noise Test, these were not recommended for further consideration. For the Dichotic Digits Test and Frequency Patterns Test, the observed mean values were relatively high at 97.6% and 93.1%, respectively, with standard deviations of no more than 7% and 14%, with only one subject unable to meet the recommended clinical criterion.

**Significance and Future Plans:** The outcomes go beyond previous studies in demonstrating that there were no, or relatively small, significant differences due to age, gender, ear or replication. In order to determine their usefulness for diagnostic purposes in a military context, the Dichotic Digits and Frequency Patterns Tests should be applied to two groups of subjects who complain of persistent hearing problems, one group with confirmed mild to moderate hearing loss and the other with negative findings on peripheral auditory testing, both screened for neurological disease. Ideally, in those with hearing problems due to peripheral pathology, scores on both tests would fall within the normal range. In those without peripheral pathology, scores falling below published norms would be suggestive of central pathology. Additional tests would be necessary to confirm the presence, site and extent of the lesion.

# Sommaire

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## Indices comportementaux du traitement de l'information par les voies auditives centrales

Sharon M. Abel; Dan van der Werf; DRDC TM 2009-026; R & D pour la défense Canada – Toronto.

**Introduction :** Les audiologistes font passer des tests non effractifs afin de déterminer l'emplacement (oreille moyenne, cochlée ou huitième nerf) et l'ampleur des troubles auditifs périphériques. Ces tests consistent généralement à mesurer les seuils de conduction aérienne et de conduction osseuse, le seuil d'intelligibilité, le seuil de discrimination des mots et la tympanométrie. Ils peuvent comprendre une évaluation de la réponse évoquée auditive du tronc cérébral ou d'émissions oto-acoustiques si on soupçonne une lésion du tronc cérébral, même si ni l'une ni l'autre ne permet de détecter une atteinte du tronc cérébral supérieur ou du cortex. Il se dégage de récentes études que divers tests psycho-acoustiques, comme le test d'écoute dichotique (de chiffres), le test des patrons de durée, le test des patrons de fréquence et le test de détection du silence, permettent de différencier les troubles auditifs périphériques des troubles auditifs centraux. La recherche dont il est question ici a porté sur l'effet du vieillissement, du sexe, de l'oreille et de la pratique sur les résultats de ces tests et comparé les résultats aux normes publiées à l'égard de jeunes adultes. En dernière analyse, l'objectif visé consistait à déterminer si ces tests pouvaient être utiles pour le diagnostic d'un trouble auditif central dans les cas où on a écarté la possibilité d'un trouble auditif périphérique mais où des problèmes d'audition persistent. Deux groupes de 12 sujets âgés de 18 à 39 ans et de 40 à 60 ans, respectivement, ont passé des tests. La moitié des membres de chaque groupe étaient de sexe masculin, l'autre, de sexe féminin. Tous parlaient couramment l'anglais, avaient une vision normale, avec ou sans correction, et une audition normale. De plus, ils n'avaient aucun antécédent de pathologie de l'oreille, de trouble neurologique ou de traumatisme crânien. Les sujets ont été testés individuellement dans une cabine insonorisée. Il s'agissait de tests offerts sur le marché sur disque compact (CD), monoauriculaires ou binauriculaires diffusés, à un niveau d'écoute confortable. Tous les tests, sauf le test de détection du silence, ont été présentés deux fois. Les sujets ont noté leurs réponses à la main sur des formulaires.

**Résultats :** L'âge, le sexe, l'oreille ou la répétition n'a eu aucun effet sur les résultats. Ainsi, on a calculé la moyenne des données relatives à l'oreille et à la répétition chez le même sujet et mis en commun les résultats des quatre groupes. On a observé une bonne concordance entre les moyennes et écarts types et les valeurs publiées à l'égard de jeunes adultes. Toutefois, étant donné l'incidence élevée (25 %) de sujets dont le score aurait été jugé anormal et l'intervalle relativement vaste des scores obtenus au test des patrons de durée, et vu le taux de réussite publié relativement faible au test de détection du silence des sujets présentant un trouble du système nerveux auditif central, il n'est pas recommandé d'envisager de recourir à ces deux tests. Dans le cas du test d'écoute dichotique (des chiffres) et du test des patrons de fréquence, les moyennes observées étaient relativement élevées, soit de 97,6 % et 93,1 %, respectivement, les écarts types étaient d'au plus 7 % et 14 %, et seul un sujet n'as pu satisfaire au critère clinique recommandé.

**Importance et projets futurs :** Cette recherche montre, mieux que les études antérieures, que l'âge, le sexe, l'oreille ou la répétition, n'a pour ainsi dire aucun effet réel sur les résultats. Si l'on

voulait déterminer l'utilité des tests à des fins diagnostiques dans un contexte militaire, il y aurait lieu d'administrer le test d'écoute dichotique (des chiffres) et le test des patrons de fréquence à deux groupes de sujets qui se plaignent de problèmes auditifs persistants. Un des groupes devrait comprendre des cas confirmés de perte auditive légère à modérée; l'autre devrait être constitué de sujets ayant obtenu des résultats négatifs à un test de dépistage de troubles auditifs périphériques. Les deux groupes devraient avoir subi un dépistage de troubles neurologiques. Idéalement, les sujets qui présentent des problèmes auditifs imputables à un trouble de l'audition périphérique devraient obtenir des résultats normaux aux deux tests. Chez les sujets ne présentant pas de trouble auditif périphérique, l'obtention d'un score inférieur aux normes publiées évoquerait la possibilité d'un trouble du système auditif central. Dans ce cas, il faudrait procéder à d'autres tests pour confirmer la présence, l'emplacement et l'ampleur de la lésion.

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# Table of contents

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Abstract .....	i
Résumé .....	ii
Executive summary .....	iii
Sommaire .....	iv
Table of contents .....	vii
List of figures .....	viii
List of tables .....	viii
Acknowledgements .....	ix
1 Introduction.....	1
2 Methods and materials .....	2
3 Results.....	5
4 Discussion.....	11
5 Conclusions.....	13
References .....	14
List of acronyms .....	17

## List of figures

---

Figure 1	The distribution of scores observed for the Duration Patterns Test .....	7
Figure 2	The distribution of scores observed for the Frequency Patterns Test .....	8
Figure 3	The distribution of scores observed for the Gaps-in-Noise Test.....	10

## List of tables

---

Table 1	The Double Dichotic Digits Test .....	5
Table 2	The Duration Patterns Test.....	6
Table 3	The Frequency Patterns Test.....	8
Table 4	The Gaps-in-Noise Test .....	9

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# 1 Introduction

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In current audiological practice, behavioural (non invasive) tests are administered to determine the presence and location of a lesion of the peripheral auditory pathway, i.e., the middle ear, cochlea or eighth nerve. These tests generally include but are not limited to the measurement of air and bone conduction thresholds, speech reception threshold, speech discrimination (usually in quiet), and tympanometry [1]. If the outcomes are suggestive of brainstem pathology, then the clinician may then use non behavioural tools to assess the physiological integrity of the central auditory pathway [2]. Tests in common usage measure the auditory brainstem response (ABR) and otoacoustic emissions (OAEs). For the ABR, recording electrodes are placed on the vertex of the scalp and mastoid area behind the ear to pick up electrical activity in response to trains of clicks presented over earphones. OAEs, essentially vibratory energy of the outer hair cells of the cochlea in response to sound, travel back through the oval window and cause the eardrum to vibrate. This activity is picked up by recording devices placed in the ear canal [2]. A drawback of both ABR and OAEs is that they are not affected by high brainstem or cortical lesions nor do they provide insight into difficulties the patient may be having with hearing or the perception of complex sounds.

Clinician scientists have explored the possibility of diagnosing lesions higher up in the central auditory pathway (midbrain and cortex) using behavioural tests of auditory processing. Behavioural tests take relatively little time to perform and are not costly. The impetus to develop these has come largely from difficulty diagnosing the cause of auditory dysfunction in individuals who are uncertain about what they hear, and have difficulty listening in background noise, understanding rapid or degraded speech, and following oral instructions, in spite of normal hearing [3]. Laboratory studies have shown that a number of auditory functions such as the perception of dichotic digits, frequency and duration pattern discrimination, and the detection of temporal gaps in noise are dependent on the integrity of the central auditory pathways [3-6]. These tests appear to be resistant to hearing loss of peripheral origin. However, they do not distinguish between brainstem and cerebral locus of lesion [2].

The ultimate goal of the present research was to determine whether a battery of clinical tests of central auditory pathology for which norms have been published for young adults might be useful for diagnosis in military operational settings, in cases where peripheral auditory pathology has been ruled out but hearing problems persist. In the first stage of this investigation described herein, these tests were applied to men and women screened for both hearing loss and brain pathology to determine the effects of age, gender, and practice. Outcomes were compared with previously published norms for young adults. In subsequent studies, these same data will provide a normative baseline to determine whether there are significant differences in outcome for individuals with closed head injury who may also have an acquired hearing loss due to peripheral cochlear pathology and those with only hearing loss.

## 2 Methods and materials

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### 2.1 Experimental design

The study protocol was approved in advance by the Defence Research and Development Canada (DRDC) Human Research Ethics Committee. Each subject provided written informed consent before participating. Two groups of 12 subjects (military and civilian) aged 18-39 years (Y) and 40-60 years (O), respectively, were tested. Half of each group were males and half females, allowing an assessment of the effects of both age and gender. To be admissible, volunteers were required to be fluent in English, have normal or corrected normal vision, and have no history of otological or neurological disease or head trauma. These criteria ensured that they would be able to hear and understand the spoken test materials and would have no difficulty seeing the answer forms, and that the results would not be confounded by central pathology. Volunteers were also screened for claustrophobia and the use of medications or medical conditions that might interfere with the ability to concentrate for a period of two hours. Individuals who passed the screening criteria were scheduled for a 30-minute hearing test. Those with confirmed normal hearing, i.e., hearing thresholds no greater than 25 dB HL (hearing level) in each ear at 0.5, 1, 2 and 4 kHz were invited to participate in the experiment [7].

Subjects participated in one test session that lasted approximately two hours. They were presented four different auditory tests: Dichotic Digits [2,8], Duration Patterns [4,9], Frequency Patterns [4,10], and Gaps-in-Noise [5]. Items for each test were pre-recorded on compact discs (CDs) by a male voice. A pilot study confirmed that the time between successive items in each test (5 sec) was sufficiently long for subjects to respond.

Two different versions of the Dichotic Digits Test are available. In the first version, a pair of digits is presented dichotically (i.e., a different one to each ear) over a headset and the subject writes down what he/she heard, without regard to ear. In the second version, two pairs of digits are presented in sequence dichotically and the subject writes down all four digits heard, without regard to order of presentation or ear. Both versions of the test contain three practice trials followed by 20 test trials. In the present study, each of the two versions of the test (single and double digit) was administered twice in sequence to determine the effect of practice.

The Duration Patterns and Frequency Patterns Tests examine the ability to both recognize acoustic elements and their temporal order [9]. For the Duration Patterns Test, the subject is required to discriminate between tones of different duration. On each trial, three 1000-Hz pure tones, separated by 300 ms are presented. These tone patterns are combinations of two sound durations, 250 ms (short-S) or 500 ms (long-L). Six combinations are included in the test: LLS, LSL, LSS, SLS, SLL, and SSL. The subject is required to identify the pattern heard (e.g., LLS). This test comprises six practice trials, followed by 60 test trials. In the present study, the practice trials and first 30 test trials were presented to one ear and the remaining 30 test trials to the other ear. Order of ears was counterbalanced across subjects in the group. The test was administered twice in sequence to enable assessment of the effect of practice. The ear order was reversed during the second replication.

The Frequency Patterns Test examines the subject's ability to discriminate between tones of different frequency [4]. On each trial, a series of three 150-ms pure tones, separated by 200 ms, are presented. These tone patterns are combinations of two sound frequencies, 1122 Hz (high-H) and 880 Hz (low-L). Six combinations are included in the test: LLH, LHL, LHH, HLH, HLL and HHL. The subject is required to identify the pattern heard (e.g., HLH). Two versions (different orders of the combinations over trials) of this test are available. In the present study, both versions were presented to each subject to allow an assessment of the effect of practice. Each comprised six practice trials followed by 54 test trials. The practice trials and first 27 test trials were presented to one ear and the remaining 27 test trials to the other ear. The order of ears and versions of the test were counterbalanced across subjects and replications.

The Gaps-in-Noise Test examines temporal resolution, specifically the ability to respond to rapid changes in the envelope of a sound stimulus over time [5]. The subject is required to detect relatively short discontinuities (i.e., silent gaps) in a 6-sec burst of white noise. Across a block of listening trials, the bursts contained 0-3 gaps that vary in duration (2, 3, 4, 5, 6, 8, 10, 12, 15 or 20 msec). Across the block of trials, each of these 10 gaps occurred six times for a total of 60. For each noise burst, the subject indicated the number of gaps heard, without regard to their individual durations. One version of this test was available for the present study. It comprised 42 trials including 10 trials for practice. The test was presented first to one ear and then the other. Order of ears was counterbalanced across subjects in each group. Owing to the time to administer this test, it was not replicated.

## **2.2 Subjects**

Subjects were recruited by means of an email sent to all employees of DRDC Toronto. Subsequent analyses confirmed that all had hearing thresholds that were no greater than 25 dB HL in each ear, at 0.5, 1, 2 and 4 kHz. Mean ages of the young and older male groups and young and older female groups were 24.2 years, 51.0 years, 25.7 years and 46.3 years, respectively. Independent sample t-tests [11] showed that, within each of the two age categories, the difference due to gender was not statistically significant. Subjects received compensation determined in accordance with guidelines developed at DRDC Toronto [12].

## **2.3 Apparatus**

Subjects were tested individually while seated at a small table in a double-walled sound proof booth with inner dimensions 2.64 (L) × 1.93 (W) × 1.98 (H) meters (Industrial Acoustics Corporation, Bronx, New York). The ambient noise was less than the maximum permissible for audiometric test rooms specified in ANSI Standard S3.1-1999 [13]. The four auditory tests were commercially available on CD (Audiology Illustrated, LLC, Storrs, CT). They were presented over Telephonics TDH-50P matched headphones (Telephonics Corporation, Farmingham, New York) using a Sony CDP-D500 Compact Disc Player (Sony Corporation, Tokyo, Japan) connected to an Interacoustics AC40 Clinical Audiometer (Grason-Stadler, Inc., Milford, New Hampshire). Stimulus materials were presented monaurally or binaurally at a comfortable listening level of approximately 50 decibels above hearing threshold (i.e., 50 dB HL). Subjects recorded their judgements on prepared answer forms using erasable pencil.

## **2.4 Procedure**

The four tests were presented in the same order to all subjects (Single and Double Dichotic Digits, Duration Patterns, Frequency Patterns and Gaps-in-Noise). Prior to each test, the experimenter fitted the headphones, and described the items that would be presented and the responses that were required. Subjects were instructed to record their judgements on the answer forms provided. They were told to guess if uncertain. Following the practice trials associated with each test, the experimenter checked the responses to ensure that the subjects had understood the instructions. Subjects were given a short break following the Duration Patterns Test. They were debriefed when all of the tests had been completed.

### 3 Results

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The dataset for each subject consisted of the percent correct achieved for each test by ear by replication. Repeated measures analyses of variance (ANOVA; 11] were applied to the results for each test to determine the effects of age, gender, ear and replication (where applicable).

#### 3.1 Dichotic digits test

For the single digit version of this test, responses were counted correct if written correctly on the answer form. The percentage of correct responses for each of right and left ears (out of 20) was calculated for each subject. Regardless of group (age by gender), ear (right vs left) or replication (1 vs 2), subjects achieved at least 19/20 or 95% correct. For the double digits version of the test, the total possible correct for each ear by replication was 40 (20 items by 2 digits). The results are shown in Table I for each of the four groups. Means ranged from 94.2% to 99.2%. An analysis of variance applied to the data set showed significant effects of ear ( $F_{1,20}=5.57$ ;  $p < 0.03$ ), replication ( $F_{1,20}=4.98$ ;  $p < 0.04$ ) and ear by replication by group ( $F_{1,20}=5.34$ ;  $p < 0.01$ ). Although statistically significant, the differences were relatively small. Averaged across groups, the score for the right ear exceeded that for the left by 2% and the score for Replication 2 (Rep 2) exceeded that for Replication 1 (Rep 1) by 1%. The means for the four groups in the present study compare well with the previously reported result of 97.2% for a group of 45 subjects aged 19-35 years screened for otological or neurological disease or trauma [8].

The data were then analyzed to determine whether subjects reported the four digits they had heard in a particular order. Possible orders were report of digits presented to the right ear before the left ear (RRL), left before right (LLR), first pair before second pair (1122), second pair before first pair (2211) or none of these options (random). Since group and replication were not significant, these data were collected for each of 24 subjects over 40 trials (i.e., the two replications of 20 trials). The results showed that no subject consistently used only one strategy. Averaged across subjects, the RRL, LLR, 1122 and 2211 and random strategies were used on 14%, 37%, 42%, 0% and 7% of trials, respectively. Subjects were most likely to report digits presented to the left ear before the right ear or else the first digits presented to the two ears before the second digits.

*Table 1: The Double Dichotic Digits Test.*

Group	Age (yrs)	Right Ear		Left Ear	
		Rep 1	Rep 2	Rep 1	Rep 2
Males	Y	98.3 (2.0)*	98.8 (3.1)	98.3 (3.0)	97.1 (2.9)
	O	96.7 (4.7)	97.9 (5.1)	97.1 (3.7)	95.4 (4.3)
Females	Y	97.9 (2.5)	99.2 (1.3)	94.2 (7.2)	97.9 (4.0)
	O	99.2 (1.3)	100.0 (0.0)	95.0 (4.2)	98.8 (1.4)

\*Mean percent correct (standard deviation), N=6

### 3.2 Duration patterns test

The duration pattern identified on each trial was scored as either correct or incorrect. The percentage of correct responses out of 30 was calculated within subject for each ear by replication. The results are shown for each of the four age by gender groups in Table II. Across group by ear by replication, mean scores ranged from 67.8% to 89.5% correct. A repeated measures ANOVA applied to these data showed that there were no significant effects of group or ear or replication or their interactions. Since there were no significant effects, the data for the two ears were averaged within subject and the results for the four groups were pooled. Figure 1 shows the distribution of outcomes observed for the 24 subjects. The mean value of 79.7% was relatively lower than the mean of 88.5% (right and left ear scores averaged) reported by Musiek et al. [9] for a group 50 individuals aged 19-39 years, screened for hearing loss and a history of neurologic disorders. The difference in the means likely reflects the broader dispersion of scores in the present study. The range of scores in the present study was 29.2%-100% compared with 63%-100% in the Musiek et al. study [9]. In both studies, the distributions were negatively skewed.

*Table II: The Duration Patterns Test.*

Group	Age(yrs)	Right Ear		Left Ear	
		Rep 1	Rep 2	Rep 1	Rep 2
Males	Y	87.8 (12.9)*	88.9 (20.8)	89.5 (14.2)	84.5 (20.4)
	O	73.3 (23.9)	70.0 (31.6)	67.8 (21.4)	68.9 (22.7)
Females	Y	77.8 (29.0)	73.9 (31.4)	79.5 (27.2)	75.0 (28.0)
	O	81.1 ( 9.4)	86.7 (14.3)	86.7 (14.3)	83.9 (14.5)

\* Mean percent correct (standard deviation), N=6

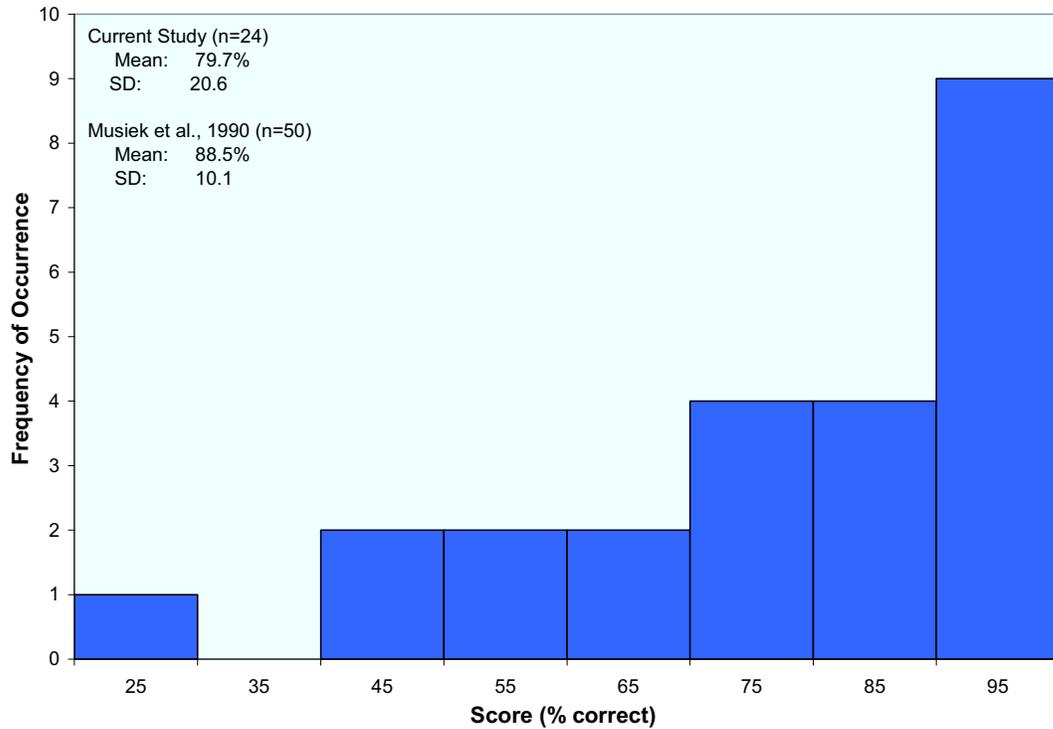


Figure 1: The distribution of scores observed for the Duration Patterns Test.

### 3.3 Frequency patterns test

The frequency pattern identified on each trial was scored as either correct or incorrect. The percentage of correct responses out of 27 was calculated within subject for each ear by replication. The results are shown for each of the four groups in Table III. Across group by ear by replication, mean scores ranged from 84.6% to 99.4%. A repeated measures ANOVA applied to these data showed that there were no significant effects of group or ear or replication or their interactions. Thus, the data for the two ears were averaged within subject and the results for the four groups were pooled. Figure 2 shows the distribution of outcomes observed for the 24 subjects. The majority of subjects (21 out of 24) obtained scores that were greater than 80%. The mean value of 92.0% was similar to the mean of 90.0% observed by Musiek [4] for a group 120 screened normal subjects, aged 17-22 years. Standard deviations of 14.2 and 20 (approx) for the two studies were similar. As in the case of the Duration Patterns Test, the distributions for the published and current study were negatively skewed.

Table III: The Frequency Patterns Test.

Group	Age(yrs)	Right Ear		Left Ear	
		Rep 1	Rep 2	Rep 1	Rep 2
Males	Y	93.0 (12.7)*	91.7 (16.1)	91.2 (15.8)	92.0 (13.7)
	O	88.2 ( 7.2)	85.2 (11.0)	85.8 (13.9)	84.6 (13.9)
Females	Y	96.9 ( 3.6)	99.4 ( 1.5)	98.8 ( 3.0)	96.9 ( 5.9)
	O	98.2 ( 3.1)	94.4 (10.4)	96.7 ( 4.3)	96.3 ( 9.1)

\*Mean percent correct (standard deviation), N=6

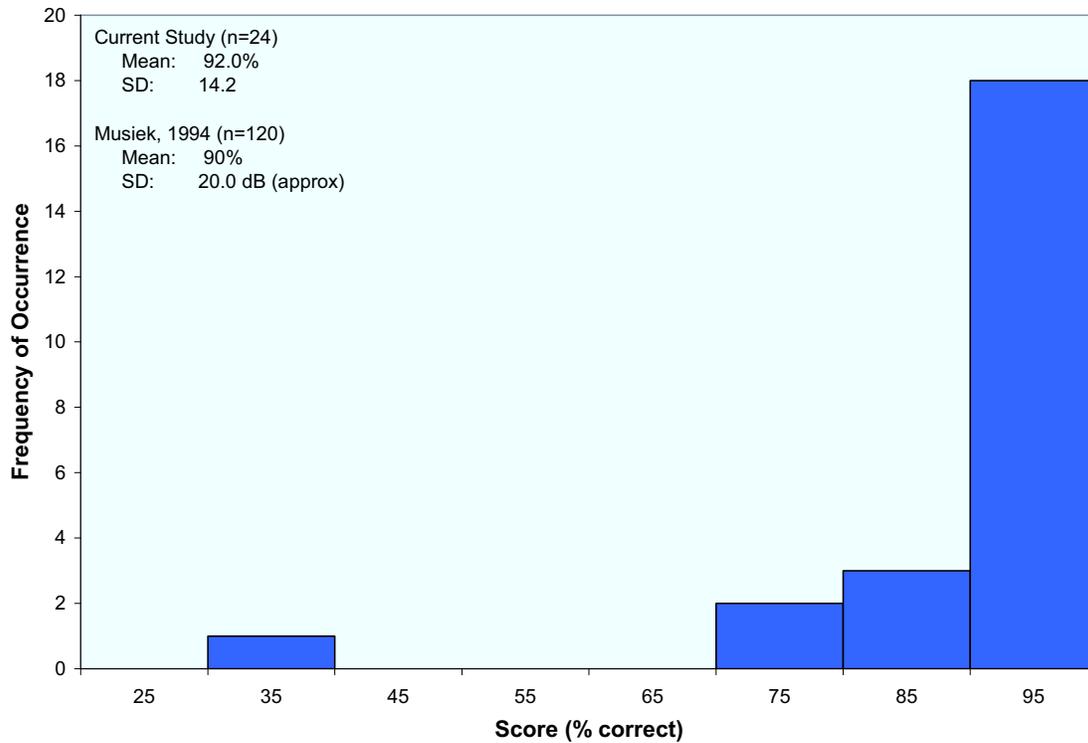


Figure 2: The distribution of scores observed for the Frequency Patterns Test.

### 3.4 Gaps-in-Noise test

In the scoring of this test, a correct detection of a gap resulted in a gain of one point for a possible total of 60 points over the block of 32 trials. One point was deducted from the total score for a missed gap or a false alarm (detecting a gap when none had been presented). The percentage of points obtained out of 60 was calculated within subject for each ear. The results are shown for the four groups in Table IV. Across group by ear, mean scores ranged from 66.4% to 77.5%. A repeated measures ANOVA applied to these data showed that there were no significant effects of group or ear or their interaction. Thus, the data for the two ears were averaged within subject and the results were pooled for the four groups. Figure 3 shows the distribution of outcomes observed for the 24 subjects. It can be seen that the distribution is symmetrical. The majority of subjects (22 out of 24) obtained scores that were between 65-79%. The mean value of 71.8% was similar to the mean of 70.0% observed by Musiek et al. [5] for a group of 50 subjects aged 13-46 years, with no audiological or neurological involvement. Standard deviations observed for the two studies were almost identical at 7.3 and 8.0, respectively.

*Table IV: The Gaps-in-Noise Test.*

Group	Age (yrs)	Right Ear	Left Ear
Males	Y	73.1 (5.2)*	70.8 (7.0)
	O	66.4 (13.7)	68.1 (9.2)
Females	Y	77.0 ( 2.2)	77.5 ( 3.1)
	O	69.2 ( 5.9)	72.5 ( 3.5)

\* Mean percent correct (standard deviation), N=6

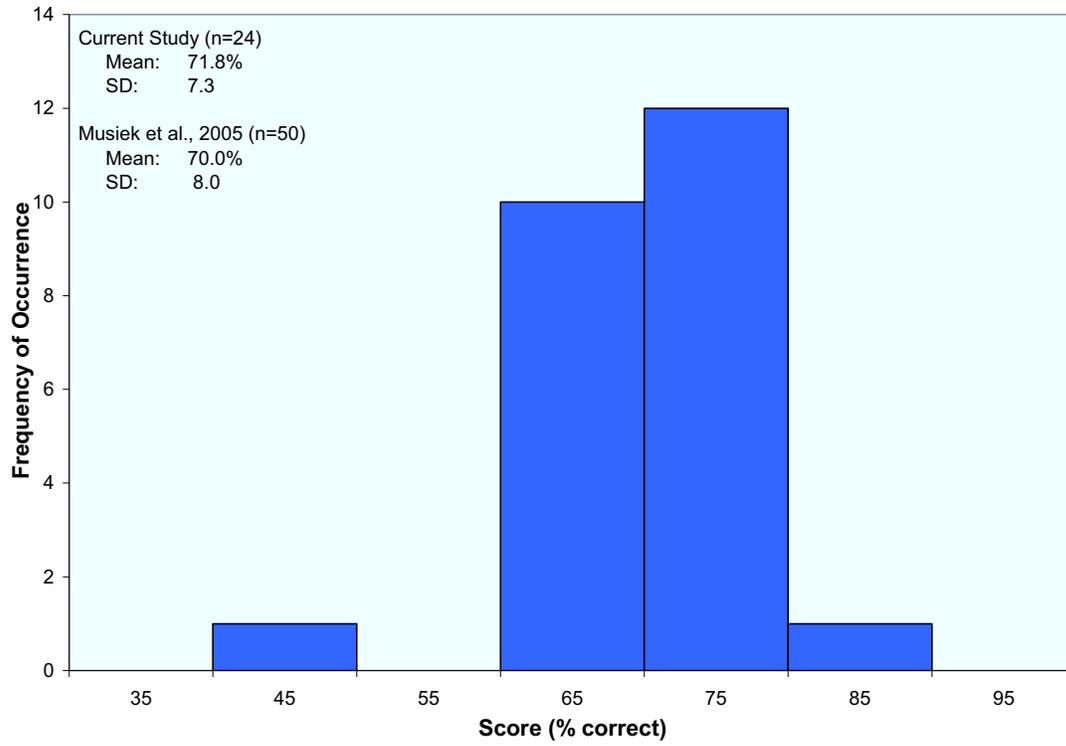


Figure 3: The distribution of scores observed for the Gaps-in-Noise Test.

## 4 Discussion

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The results of the present study are in good agreement with previously published results for young adults screened for peripheral and central auditory pathology. The outcomes go beyond previous studies in demonstrating that there are no, or relatively small, differences due to age, gender or replication. The next questions to ask are to what extent are these tests good predictors of central auditory pathology and what values should be used for clinical diagnostic purposes. For the Double Dichotic Digits Test, the recommended criterion to rule out cortical pathology in individuals without hearing loss is 90% or more. This value is the mean minus two standard deviations reported by Musiek [8]. Using this criterion, Musiek et al. [2] reported that 24 of 32 (75%) of patients with central auditory nervous system (CANS) lesions and normal hearing and 9 of 30 (30%) of patients with peripheral hearing loss (30%) failed the criterion. If an adjusted criterion of 80% correct was used, the false positive rate for individuals with hearing loss decreased to 3 of 30 (10%). In those with both hearing loss and CANS pathology, 13 of 18 (72%) showed an abnormal results with the adjusted criterion. Based on these outcomes, the authors recommended using the 90% correct criterion for subjects screened for hearing loss and the 80% criterion for patients with hearing loss. They caution that the test does not discriminate between brainstem and cortical pathology. In the present study, only one subject (an older male) failed to meet the 90% correct criterion with a score of 88.9% correct.

The preference for reporting digits presented to the left ear before the right ear (LLRR) and digits presented first in the series before those presented second (1122) for the Double Dichotic Digits Test are consistent with findings by Brainerd and co-workers that weaker items are reported first [14-16]. This effect is known as cognitive triage. According to Brainerd [16], this strategy is observed as early as six years of age and is a basic feature across the life-span. In the present study, the subjects' task was to recall all four digits regardless of ear or order. If we accept the premise that items presented to the right ear will have an advantage because they are processed by speech centres in the left brain [17], then digits presented to the left ear may be at greater risk of getting lost. As well, since there is no opportunity for rehearsal, memory traces of items presented first are more likely to decay than those presented second. Order of report for dichotic digits has not previously been examined with a view to clinical diagnosis. It may be that this information will prove to have some value for determining the site of a lesion.

For the Duration Patterns Test, Musiek et al. [9] recommend a criterion of 70% or more to rule out CANS pathology. This value is the mean minus two standard deviations observed for the normal subjects. Using this criterion, Musiek et al. [9] reported that 86% of individuals with CANS lesions and 8% of subjects with cochlear pathology were categorized as abnormal. Thus, this test is sensitive to cerebral lesions and is largely unaffected by mild to moderate hearing loss. Its ability to distinguish between brainstem and cortical lesions has not been examined. In the present study, six of twenty-four subjects (25%) failed the criterion – three in the two young groups and three in the older male group. Their scores ranged from 29% to 68%. This relatively wide range of outcomes suggests that this test might be less preferable for clinical diagnosis than the Double Dichotic Digits Test.

For the Frequency Patterns Test, a result of at least 75% is the recommended cutoff to rule out CANS pathology. This represents the 90<sup>th</sup> percentile for a group of 120 young adults with no

CANS involvement and normal hearing [4]. Musiek and Pinheiro [10] reported that 12% of patients with hearing loss of peripheral origin, 45% of patients with brainstem involvement but normal hearing and 83% of patients with lesions localized to auditory areas of the cerebrum failed the test. The authors concluded that that the test was sensitive to cortical pathology and resistant to hearing loss but could not diagnose brainstem pathology. In the present study, one subject in the young male group subject failed this criterion with a score of 37%. The outcomes of both the published and current study suggest that this test would be a suitable diagnostic tool for central auditory pathology.

For the Gaps-In-Noise Test, the recommended criterion to rule out CANS involvement is 54%. This value is equivalent to the observed mean for a group of 50 young adults screened for hearing loss and neurological involvement of 70% minus two standard deviations [5]. Musiek et al. [5] reported that 8 of 18 (44%) of subjects with CANS lesions did not meet the criterion. In spite of this relatively low rate and the fact they tested neither subjects with brainstem involvement nor those with hearing loss, they conclude that the test provides good sensitivity. They note that the perception of gaps-in-noise may be sensitive to both aging and hearing loss. In the present study, one subject in the older male group did not meet the criterion with a score of 46%. The relatively low hit rate for CANS patients and lack of data for individuals with hearing loss indicates that this test would not be suitable for diagnosing central nervous system pathology.

## 5 Conclusions

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The results of the present study, taken together with previously published findings, indicate that both the Double Dichotic Digits Test and the Frequency Patterns Test are sensitive to central auditory pathology, and not affected by aging, gender or hearing loss of peripheral origin. For the present study, observed mean values for normal subjects on these tests were relatively high at 97.6% and 93.1%, respectively, averaged across age by gender groups and replications, and also similar across subjects, i.e., the standard deviations were relatively small, no more than 7% for the Dichotic Digits Test and 14% for the Frequency Patterns Test. In order to determine their usefulness for diagnostic purposes in a military context, these should be applied to two groups of subjects who complain of hearing problems, one group with confirmed mild to moderate hearing loss and the other with negative findings on peripheral auditory testing, both screened for neurological disease. Ideally, in those with hearing problems due to peripheral pathology, scores on both tests would fall within the normal range. In those without peripheral pathology, scores falling below published norms would be suggestive of central pathology. Additional tests would be necessary to confirm the presence, site and extent of the lesion.

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## List of acronyms

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ABR	Auditory brainstem response
ANOVA	Analysis of variance
CANS	Central auditory nervous system
CDs	Compact discs
dB	decibels
DRDC	Defence Research and Development Canada
HL	Hearing level
OAEs	Otoacoustic emissions

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(U) This research examined the effect of aging, gender, ear and practice on the outcomes of a battery of behavioural tests used in clinical practice to diagnose pathology of the central auditory system. The test battery included the Dichotic Digits Test, Duration Patterns Test, Frequency Patterns Test and Gaps-in-Noise Test. The ultimate goal was to determine whether such tests might be useful in diagnosing pathology of central origin in cases where peripheral auditory pathology has been ruled out but hearing problems persist. Two groups of 12 subjects aged 18–39 years and 40–60 years, respectively, were tested. Half of each group were males and half females. All were fluent in English, had normal or corrected normal vision and normal hearing, and had no history of otological or neurological disease or head trauma. Subjects were tested individually in a sound proof booth. The test materials were commercially available on compact discs (CDs). These were presented at a comfortable listening level. All but the Gaps-in-Noise Test were presented twice. Subjects recorded their responses using paper and pencil. The results showed that there were no significant effects of age, gender, ear or replication. Thus, the outcomes for the 24 subjects were pooled. Means and standard deviations were similar to published norms. However, based on the high incidence (25%) of subjects whose scores would have been judged abnormal and the relatively wide range of outcomes for the Duration Patterns Test, and the published low hit rate for individuals with central auditory nervous system pathology for the Gaps-in-Noise Test, these two tests were not recommended for further consideration.

(U) Cette recherche portait sur l'effet du vieillissement, du sexe, de l'oreille et de la pratique sur les résultats d'une batterie de tests comportementaux utilisés en clinique pour le diagnostic des troubles du système auditif central. La batterie comprenait le test d'écoute dichotique (de chiffres), le test des patrons de durée, le test des patrons de fréquence et le test de détection du silence. En dernière analyse, il s'agissait de déterminer si ces tests pouvaient être utiles pour le diagnostic d'un trouble auditif central dans les cas où a écarté la possibilité d'un trouble auditif périphérique mais où des problèmes d'audition persistent. Deux groupes de 12 sujets âgés de 18 à 39 ans et de 40 à 60 ans, respectivement, ont passé les tests. La moitié des membres de chaque groupe étaient de sexe masculin, l'autre, de sexe féminin. Tous parlaient couramment l'anglais, avaient une vision normale, avec ou sans correction, et une audition normale. Ils n'avaient en outre aucun antécédent de pathologie de l'oreille, de trouble neurologique ou de traumatisme crânien. Les sujets ont été testés individuellement dans une cabine insonorisée. Il s'agissait de tests offerts sur le marché sur disque compact (CD), diffusés à un niveau d'écoute confortable. Tous les tests, sauf le test de détection du silence, ont été présentés deux fois. Les sujets ont noté leurs réponses à la main (crayon-papier). Il ressort de l'expérience que l'âge, le sexe, l'oreille et la répétition n'avaient aucun effet significatif sur les résultats. Aussi, les résultats des 24 sujets ont été mis en commun. Les moyennes et les écarts types étaient comparables aux normes publiées. Toutefois, étant donné l'incidence élevée (25 %) de sujets dont le score aurait été jugé anormal et l'intervalle relativement vaste des scores obtenus au test des patrons de durée, et vu le taux de réussite publié relativement faible au test de détection du silence des sujets présentant un trouble du système nerveux auditif central, il n'est pas recommandé d'envisager de recourir à ces deux tests.

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(U) central auditory lesions; non invasive tests; normative data; age, gender and replication effects.

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