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ORIGINAL PAPER

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AUDITORY TEMPORAL PROCESSING TESTS – NORMATIVE DATA FOR POLISH-SPEAKING ADULTS

TESTY SŁUCHOWEGO PRZETWARZANIA CZASOWEGO – WARTOŚCI NORMATYWNE U DOROSŁYCH POSŁUGUJĄCYCH SIĘ JĘZYKIEM POLSKIM

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Abstract

Background: Several subjects exposed to neurotoxins in the workplace need to be assessed for central auditory deficit. Although central auditory processing tests are widely used in other countries, they have not been standardized for the Polish population. The aim of the study has been to evaluate the range of reference values for 3 temporal processing tests: the duration pattern test (DPT), the frequency pattern test (FPT) and the gaps in noise test (GIN). **Material and Methods:** The study included 76 normal hearing individuals (38 women, 38 men) at the age of 18 to 54 years old (mean ± standard deviation: 39.4±9.1). All study participants had no history of any chronic disease and underwent a standard ENT examination. **Results:** The reference range for the DPT was established at 55.3% or more of correct answers, while for the FPT it stood at 56.7% or more of correct answers. The mean threshold for both ears in the GIN test was defined as 6 ms. In this study there were no significant associations between the DPT, FPT and GIN results and age or gender. Symmetry between the ears in the case of the DPT, FPT and GIN was found. **Conclusions:** Reference ranges obtained in this study for the DPT and FPT in the Polish population are lower than reference ranges previously published for other nations while the GIN test results correspond to those published in the related literature. Further investigations are needed to explain the discrepancies between normative values in Poland and other countries and adapt tests for occupational medicine purposes. Med Pr 2015;66(2):145–152

Key words: auditory temporal processing, DPT, FPT, GIN, normative values

Streszczenie

Wstęp: Wiele osób pracujących w narażeniu na substancje neurotoksyczne wymaga badań w kierunku ośrodkowych zaburzeń słyszenia. Mimo że używane w tym celu testy ośrodkowego przetwarzania słuchowego są szeroko stosowane w innych krajach, nie zostały dotąd wystandaryzowane dla populacji polskiej. Celem pracy było określenie zakresu wartości referencyjnych dla 3 testów przetwarzania czasowego: testu wzorcu długości (duration pattern test – DPT), testu wzorcu częstotliwości (frequency pattern test – FPT) i testu wykrywania przerw w szumie (gaps in nosie – GIN). **Materiał i metody:** Badaniami objęto 76 osób z prawidłowym słuchem (38 kobiet, 38 mężczyzn) w wieku 18–54 lata (średnia ± odchylenie standardowe: 39,4±9,1). Żaden z uczestników badania nie cierpiał w przeszłości na chorobę przewlekłą, a wynik badania otolaryngologicznego u każdego z uczestników był w normie. **Wyniki:** Obliczono, że przedział wartości prawidłowych dla DPT wynosi 55,3–100%, a dla FPT – 56,7–100% poprawnych odpowiedzi. Przybliżony średni próg detekcji dla obu uszu w teście GIN został ustalony na poziomie 6 ms. Nie stwierdzono istotnych zależności między wynikami DPT, FPT i GIN a wiekiem lub płcią. Stwierdzono symetrię DPT, FPT i GIN dla obu uszu. **Wnioski:** Przedziały wartości referencyjnych dla DPT i FPT w populacji polskiej są niższe niż wcześniej publikowane zakresy referencyjne dla innych narodów, natomiast wyniki GIN są zgodne z publikowanymi danymi literaturowymi. Konieczne są dalsze badania w celu wyjaśnienia rozbieżności między wartościami normatywnymi w Polsce a w innych krajach oraz dostosowanie testów do potrzeb medycyny pracy. Med. Pr. 2015;66(2):145–152

Słowa kluczowe: przetwarzanie czasowe, DPT, FPT, GIN, wartości normatywne

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INTRODUCTION

Several occupational processes involving chemicals may cause toxic encephalopathy. Occupational exposure to toxic agents may induce adverse effects on human hearing, that are associated with cochlear pathology and dysfunction of the Central Auditory Nervous System (CANS). Although tests of the central auditory processing are widely used in other countries, they have not been standardized for the Polish-speaking population.

The Central Auditory Processing (CAP) refers to the perceptual processing of auditory information in the central nervous system (CNS) and the neurobiologic activity that underlies that processing [1]. Auditory processing disorders (APD) may be described as deficits in the effectiveness indicating how successfully the CNS utilizes auditory information, including inter-hemispheric communication [2].

According to the American Speech-Language-Hearing Association (ASHA), the APD includes the auditory mechanisms that underlie the following abilities or skills: auditory discrimination; temporal aspects of audition; sound localization and lateralization; auditory performance in competing acoustic signals and auditory performance with degraded acoustic signals. The auditory processing disorders may be diagnosed if difficulties in the processing of auditory information in the CNS are demonstrated by poor performance in one or more of the above skills [1]. The auditory temporal processing may be defined as the perception of the sound in the restricted time interval [3].

Although temporal processing is observed at many levels of the auditory pathway, it depends mainly on cortical and inter-hemispheric processing [4]. Categories of temporal processing include temporal ordering or sequencing, temporal resolution, temporal integration and temporal masking. There are no clinically available tests of temporal integration and temporal masking, so audiologists incorporate tests of temporal sequencing and temporal resolution in their clinical practice [3]. Temporal ordering and temporal resolution tests are recommended as a part of auditory processing screening test battery [1]. Time processes such as temporal sequencing and temporal resolution play a crucial role in the recognition of acoustic features of speech such as prosodic, accent and rhythm details. Temporal resolution is directly connected with speech perception, hence most patterns in speech sounds are based on millisecond time differences [3].

Temporal ordering refers to the processing of 2 or more auditory stimuli in their order of occurrence in time. The most widely used clinical tests of temporal sequencing or ordering, which gained widespread acceptance, are the duration pattern test (DPT) and the frequency pattern test (FPT) [5].

Temporal resolution refers to the shortest duration of time, in which subjects can discriminate between 2 auditory signals [3]. Temporal resolution is considered to be important for the identification of fine differences in speech signals [6].The most commonly used tests of temporal resolution measure gap detections in an ongoing sound. The gaps-in-noise test (GIN), introduced by Musiek et al., assesses the detection of silence intervals (gaps) that are embedded in white noise [7].

Even non-verbal auditory test performance may depend on language features. It has been shown that speakers of tonal languages (e.g., Chinese) have better abilities in imitating and discriminating musical pitch than speakers of non-tonal languages [8]. It has been shown that processing of duration of non-speech sounds is enhanced in the case of speakers of a quantity language (Finnish) and non-quantity language musicians (French musicians) but not in the case of non-quantity language non-musicians [9]. According to the confounding effect of the language experience, Dillon et al. stated that clinicians of each country should elaborate their own test batteries to evaluate the APD [10].

Although there are a lot of available test batteries for English-speaking populations (e.g., the screening test for the auditory processing disorders (SCAN), the Multiple Auditory Processing Assessment (MAPA)), and a lot of work in this area has been done in non English-speaking countries [11,12], there is still a lack of auditory processing test norms in other countries, including Poland.

The aim of this study has been to evaluate the range of reference values of the DPT, FPT and GIN and to check gender, age and ear symmetry dependence on the performance on these tests in normal hearing individuals.

MATERIAL AND METHODS

Subjects

Initially, the study sample included 100 participants with no history of chronic disease and standard ENT examination. In the 1st stage of the study a detailed medical history was taken. Subjects were asked particularly about their history of ear disease, subjective hearing deterioration, difficulties to understand speech in noisy environments, exposure to noise and organic solvents, and language or learning disabilities. Only individuals reporting absence of the problems mentioned above were included in the study. Subsequently, the ENT examination and pure-tone audiometry (PTA) was carried out. In a sound-proof booth hearing thresholds were obtained at 250–8000 Hz for air conduction and 500–4000 Hz for bone conduction. Only participants with bilateral hearing thresholds equal to or better than 20 dB HL at all tested frequencies were included in the study group.

According to Musiek et al., before carrying out the temporal processing tests, the usage of practice items is needed [13,14]. Thus, before each test administration initial practice was used to verify if the subject had understood the idea of the test. The scores in this initial task were not included in the total test results.

Based on the initial criteria, 24 subjects were excluded from the study: 2 subjects – due to the history of health problems as mentioned above, 15 subjects – due to abnormal PTA results and 4 individuals – due to abnormal initial practice testing. The final group comprised 76 normal hearing individuals (38 women and 38 men) at the age of 18 to 54 years old (mean ± standard deviation: 39.4±9.1).

Methods

Temporary processing tests (DPT, FPT and GIN) were taken monaurally on each person, and were performed in a quiet room after making the subject familiar with each task.

The duration pattern test

The duration pattern test was conducted by using a commercially available compact disc from Auditec, St. Louis. In this study, a set of 30 sequences of 2 tones differing in their duration (250 ms and 500 ms), arranged in 3-tone tokens, were presented monaurally to each ear (at 50 dB HL above the subject's threshold for 1000 Hz in the PTA). The tone frequency was 1000 Hz with a rise/fall time of 10 ms, and with an inter-tone interval of 300 ms. Subjects were asked to verbalize the duration of each tone in the sequence (e.g., "short–long–long"). The answers were registered on the score sheet and the percentage rate of correct answers was calculated.

The frequency pattern test

The frequency pattern test was conducted by using a commercially available compact disc from Auditec, St. Louis. In this study, a set of 30 sequences of 2 tones differing in their pitch (880 Hz and 1122 Hz), arranged in 3-tone tokens, was presented monaurally to each ear (at 50 dB HL above the subject's threshold at 1000 Hz in the PTA). The tone duration was 150 ms with a rise/fall time of 10 ms, and with an inter-tone interval of 200 ms. Subjects were asked to name the pitch of each tone in the sequence (e.g., "high-low-high"). The answers were registered on the score sheet and the percentage rate of correct answers was calculated.

The gaps in noise test

The gaps in noise test was conducted by using a commercially available compact disc from Auditec, St. Louis. Stimuli were presented monaurally at 50 dB HL above the subject's threshold at 1000 Hz in the PTA. This test consisted of series of 36 different 6-s segments of white noise, each containing 0–3 gaps. The inter-stimulus interval between noise segments was 5 s. The gap durations in this test were (ms): 2, 3, 4, 5, 6, 8, 10, 12 and 20 with each silence gap duration occurring 6 times. The test contained a total of 60 gaps per list. While undergoing the test, the subject was required to listen for any silence gap that might or might not occur within each noise segment. As soon as the noise segment was finished the subject had to respond how many gaps (0–3) were contained in the segment of noise that was presented.

The approximate threshold was used for analysis by considering the following 2 criteria:

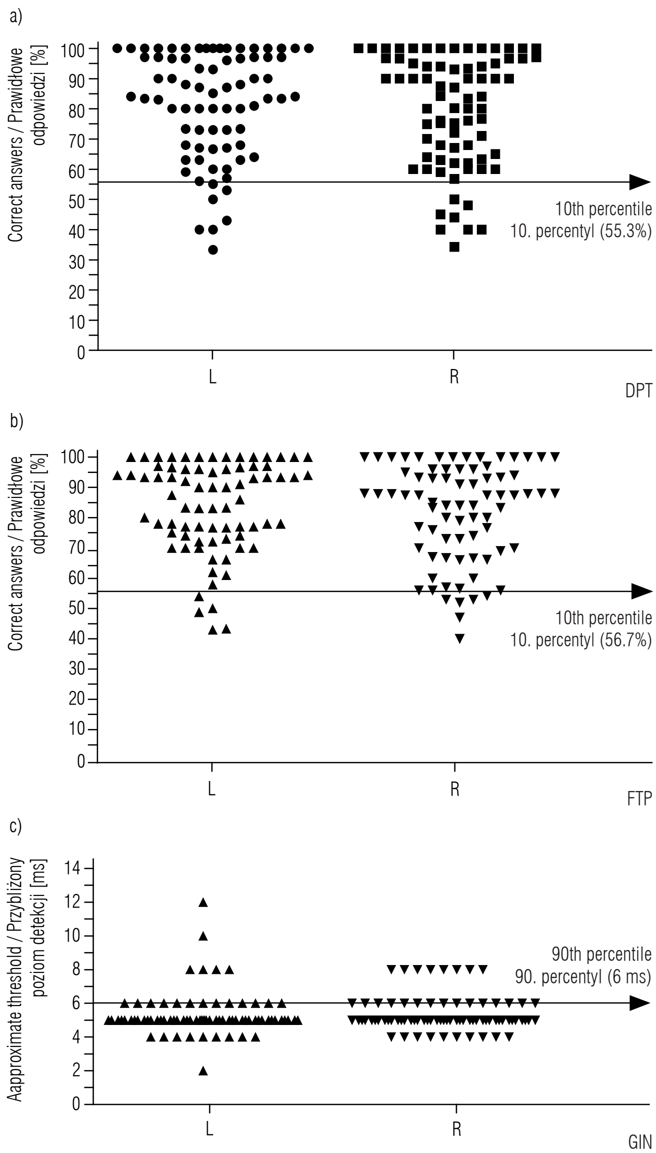
1. At least 4 out of 6 gaps are correctly identified.
2. Performance for longer gap durations is not worse than 4 out of 6 gaps correctly identified.

There are 2 possible ways of analyzing the GIN results – the approximate threshold (ATh) and the overall percent of correct answers. The approximate threshold is preferred by the test authors because of having better sensitivity and specificity [7]. False positive responses were counted and subtracted from the number of gap durations identified per ear when more than 2 false responses occurred.

The study was approved by the Medical Ethical Committee of the Nofer Institute of Occupational Medicine, Łódź, Poland.

Statistical methods

The percentage rate of correct answers in the case of the DPT, FPT and GIN were analyzed independently for left and right ears. In the 1st step, distributions of study variables were tested. Since, a skewed distribution was clearly visible, median values (with 10th and 90th percentile) were chosen as adequate central tendency (distribution) (see Figure 1 and Table 1). Results above 10th percentile were defined as reference for the DPT and FPT, results above 90th percentile were defined as reference scores for the GIN. To compare the GIN results with other literature data, mean ±2 standard deviations were additionally calculated.



L – left ear / ucho lewe, R – right ear / ucho prawe.
DPT – duration pattern test / test wzorca długości, FPT – frequency pattern test / test wzorca częstotliwości, GIN – gaps-in-noise test / test wykrywania przerw w szumie.

Fig. 1. Results of DPT, FPT and GIN tests in both ears
Ryc. 1. Wyniki testów DPT, FPT i GIN dla obojga uszu

RESULTS

Taking into account 10th percentile, the DPT reference cut-offs were 49.4%, 55.7% and 55.3% for right, left and both ears, respectively (Table 1 and Figure 1A). Taking into account 10th percentile, the FPT reference cut-offs were 56%, 61.7% and 56.7% for right, left and both ears, respectively (Table 1 and Figure 1A). Reference cut-offs for the GIN, defined in 90th percentile, were 8, 6 and 6 for right, left and both ears, respectively (Table 1 and Figure 1C).

To compare our results with the studies of other authors we additionally assessed the GDT normative values using mean ±2 standard deviations. The mean GDT in our study stood at 5.3 ms for the left ear (< 7.9 as normative value taking into account 2 standard deviations) and 5.4 ms for the right ear (< 7.6 as normative value taking into account 2 standard deviations).

There were no significant associations between the DPT/FPT/GIN results and age (Table 2) and gender (Table 3). We showed a significant linear correlation between the left and right ear in the case of the DPT (Spearman coefficient: 0.83), the FPT (Spearman coefficient: 0.63) and the GIN (Spearman coefficient: 0.69). A significant correlation between the DPT and FPT results for both ears was observed (Table 2).

DISCUSSION

Since there were no reference values available for the Polish population, in this study we have estimated the results of 3 temporal processing tests (DPT, FPT and GIN) in 76 normal hearing Polish adult subjects.

The duration pattern test was firstly administrated by Musiek et al. in 1990 [14]. The authors showed that sensitivity and specificity of this test with respect to cerebral lesions was at the level of 83% [13,14]. It indicates that this test may be a valuable method for the evaluation of the central auditory dysfunction.

The frequency pattern test was firstly described in 1972 by Pinheiro and Ptacek [15]. Similarly to the DPT its sensitivity and specificity with respect to cerebral lesions were high and were estimated respectively at 86% and 92% with respect to cerebral lesions [15]. As in other studies, both pattering tests in this study were administrated monaurally.

The gaps-in-noise test was firstly administrated by Musiek et al. in 2005, but its value in the evaluation of cerebral lesions has not been established so far [7].

Reference values

The tests scores did not follow a normal distribution in this study, which is also reported by other authors [11,12,16]. For that reason norms for tests in our study are suggested to be 10th percentiles as cut-off scores to distinguish between "normal" and "abnormal" results for pattern tests and results above 90th percentile have been defined as reference scores for the GIN.

Table 1. Central tendency and distribution of study variables
Tabela 1. Centralne miary położenia i miary rozproszenia badanych zmiennych

Parameter Parametr	Correct answers Prawidłowe odpowiedzi [%]						GIN [ms]		
	DPT			FPT					
	L	R	total ogółem	L	R	total ogółem	L	R	total ogółem
Observations / Obserwacje [n]	76	76	152	76	76	152	76	76	152
Minimal value / Wartość minimalna	33.30	36.00	33.30	43.00	40.00	40.00	2.00	4.00	2.00
25th percentile / 25. percentyl	67.20	63.50	66.70	74.00	69.20	72.20	5.00	5.00	5.00
Median / Mediana	84.00	83.30	83.60	88.30	86.60	86.60	5.00	5.00	5.00
75th percentile / 75. percentyl	97.00	96.20	96.70	96.40	95.70	96.00	5.75	6.00	6.00
Maximal value / Wartość maksymalna	100.00	100.00	100.00	100.00	100.00	100.00	12.00	8.00	12.00
10th percentile / 10. percentyl	55.70	49.40	55.30	61.70	56.00	56.70	4.00	4.00	4.00
90th percentile / 10. percentyl	100.00	100.00	100.00	100.00	100.00	100.00	6.00	8.00	6.00
Mean / Średnia	81.30	79.20	80.20	83.60	81.40	82.50	5.30	5.40	5.40
Standard deviation / Odchylenie standardowe	17.80	18.60	18.20	15.20	16.10	15.70	1.33	1.07	1.20
Standard error / Błąd standardowy	2.04	2.13	1.47	1.74	1.85	1.27	0.15	0.12	0.097

Abbreviations as in Figure 1 / Skróty jak na rycinie 1.

Table 2. Linear correlation between DPT, FPT and GIN results in both ears, and age of participants*
Tabela 2. Korelacja liniowa między wynikami testów DPT, FPT i GIN w obu uszach i wiekiem badanych pacjentów*

Test	Age [years] Wiek [w latach]	Linear correlation Korelacja liniowa								
		DPT(L)	DPT(R)	DPT	FPT(L)	FPT(R)	FPT	GIN(L)	GIN(R)	GIN
DPT(L)										
R	0.112	1	–	–	–	–	–	–	–	–
P	0.335	–	–	–	–	–	–	–	–	–
DPT(R)										
R	0.156	0.830	1	–	–	–	–	–	–	–
P	0.177	< 0.001	–	–	–	–	–	–	–	–
DPT										
R	0.112	1	0.830	1.000	–	–	–	–	–	–
P	0.335	–	< 0.001	–	–	–	–	–	–	–
FPT(L)										
R	–0.126	0.204	0.274	0.204	1	–	–	–	–	–
P	0.280	0.077	0.017	0.077	–	–	–	–	–	–
FPT(R)										
R	–0.031	0.229	0.283	0.229	0.634	1	–	–	–	–
P	0.788	0.047	0.013	0.047	< 0.001	–	–	–	–	–
FPT										
R	–0.126	0.204	0.274	0.253	1	0.634	1	–	–	–
P	0.280	0.077	0.017	0.002	–	< 0.001	–	–	–	–
GIN(L)										
R	0.049	–0.128	–0.094	–0.128	–0.139	–0.165	–0.139	1.000	–	–
P	0.672	0.271	0.417	0.271	0.231	0.155	0.231	–	–	–
GIN(R)										
R	–0.051	–0.211	–0.165	–0.211	–0.092	–0.121	–0.092	0.694	1	–
P	0.663	0.068	0.155	0.068	0.430	0.298	0.430	< 0.001	–	–
GIN										
R	0.049	–0.128	–0.094	–0.155	–0.139	–0.165	–0.134	1	0.694	1.000
P	0.672	0.271	0.417	0.056	0.231	0.155	0.099	–	< 0.001	–

R – correlation coefficient / współczynnik korelacji, P – probability / prawdopodobieństwo.
Other abbreviations as in Figure 1 / Inne skróty jak na rycinie 1.
* Data is presented with Spearman coefficient / Dane przedstawiono przy pomocy współczynników korelacji Spearmana.

Table 3. Associations between DPT, FPT and GIN results in both ears and gender of participants
Tabela 3. Zależność między wynikami testów DPT, FPT i GIN w obu uszach a płcią badanych

Test	Females Kobiety			Males Mężczyźni			p
	Me	lower quartile dolny kwartyl	upper quartile górny kwartyl	Me	lower quartile dolny kwartyl	upper quartile górny kwartyl	
DPT(L)	83.65	73.0	97.0	85.0	67	97	0.7979
DPT(R)	90.00	63.3	96.6	78.5	65	94	0.5557
DPT	83.65	73.0	97.0	85.0	67	97	0.7979
FPT(L)	91.50	77.0	96.6	83.0	72	96	0.3093
FPT(R)	86.60	70.0	94.0	84.0	67	96	0.508
FPT	91.50	77.0	96.6	83.0	72	96	0.3093
GIN(L)	5.00	5.0	6.0	5.0	5	5	0.3801
GIN(R)	5.00	5.0	6.0	5.0	5	5	0.1228
GIN	5.00	5.0	6.0	5.0	5	5	0.3801

Me – median / mediana.
Other abbreviations as in Figure 1 / Inne skróty jak na rycinie 1.

Other researchers have used the same boundary criteria for pattering tests (10th percentile to distinguish between "normal" and "abnormal" results) [11,12,16], however in the literature, authors define the GIN results using mean ±2 standard deviations as cut-off scores to distinguish between "normal" and "abnormal" results [7,16–18].

Normative values for the DPT, published by Musiek at al. [13], have been established at 70% or more of correct answers. Reference values for the FPT, according to Musiek et al., have been reported to stand at 75% or more of correct answers [13]. Fuente at al., whose study included 40 normal hearing Chilean adults at the age of 18 to 50 years old, established the reference range at the level of 85.5% or more of correct answers for the DPT, and 80% or more of correct answers for the FPT [11]. The results of Neijenhuis et al. in the study which included 28 Dutch adults with normal hearing at the age of 18 to 47 years old, were 90% for the DPT and 89% for the FPT [12]. In the study of Neijenhuis et al. [12] tones in both pattern tests were presented binaurally, while Musiek et al. [13], Fuente et al. [11] and authors of this research used monaural tone presentation. Norms established in this study are significantly lower (55.3% for the DPT and 56.7% for the FPT) in comparison to studies mentioned above. One of the reasons for that fact may be a slightly different methodology used in our study than in previous investigations. In the case of the FPT, Fuente et al. used higher pitch of one of the tones (1430 Hz in comparison to 1122 Hz used in this study), so tones were easier to distinguish. Neijenhuis et al. and Fuente et al. [11,12] used a relatively low number of subjects as compared to our study. It may be hypothesized that the ceiling effect in the DPT and the FPT results observed in those studies was due to the extent of the training prior to the test performance.

The fact that reference ranges obtained in this study for the DPT and the FPT in the Polish population are lower than reference ranges previously published for speakers of other languages demands further investigation.

Norms for the GIN, published by Musiek et al., were suggested to be the mean ATh at 4.8 ms for the left ear and 4.9 ms for the right ear [7]. Musiek et al. used mean ±2 standard deviations as cut-off scores to distinguish between "normal" and "abnormal" results. The GDT in our study defined as 90th percentile stands at 6 ms for the left ear and 8 ms for the right ear. The mean ATh for both ears defined as 90th percentile stands at 6 ms. The mean GDT in our study defined as mean ±2 standard deviations stands at 5.3 ms for the left ear and 5.4 ms for the right ear. Samelli and Schochat assessed the mean GDT to stand at 4.19 ms [16]. In the study of Zaidan et al. the GDT standing at 4.88 ms (left ear) and 5.38 ms (right ear) were reported [17]. In the study of Helfer and Vargo [18] the mean ATh stood at 4.4Z2 ms for a younger group and 4.92 ms for an older group. Results obtained in this study correspond to those ones found in the literature.

Age

In this study there were no significant associations between the DPT, FPT results and age, which is in accordance with other authors [10,11,13].

Similarly, there were no significant associations between the GIN results and age in this study. However literature data related to this test is equivocal. According to Musiek et al. [7] the GIN stimulus simplicity (broadband noise) causes that differences due to age are unlikely. A study of these authors confirmed no significant difference on the GIN performance between young and middle-aged subjects. However, there are studies that have indicated the higher GDTs in the case of older subjects in comparison to younger control subjects [19,20]. Although, other investigators have questioned this finding [21]. Lister et al. [22] and He et al. [20] have not found any significant difference between the GDTs in the case of young and middle-aged individuals, either. On the other hand, results of the study of Helfer and Vargo have documented a difference in the GIN results in the case of younger and middle-aged women [18]. Probably these results are connected with a small amount of high-frequency hearing loss in the older group in that study. Previous studies have demonstrated a connection between high-frequency hearing loss and reduced gap detection ability [23,24].

Gender

We did not find statistically significant differences between males and females in the FPT, DPT and GIN results, which had also been the case with the studies of Musiek et al. [6,13]. On the other hand, in the study of Samelli and Schochat, which included 100 Brazilian adults, male participants indicated a significantly better GDT than women in the GIN test [16]. Zaidan et al. also found a better GIN performance in the case of males. However, the male participants were music therapy students, which can justify the sex differences in this study [17].

Ear symmetry

Results from this investigation demonstrate symmetry between the ears in the DPT, FPT and GIN, which corresponds to the results reported in other papers [7,11–13].

The elaboration of Polish normative values for the DPT, FPT and GIN is very important for introduction of these tests to the occupational medicine practice. Studies have shown that the auditory temporal processing can be impaired in subjects exposed, among others, to industrial solvents [25]. The most ototoxic substance was styrene [26]. The results of the DPT, FPT, Hearing in Noise Test (HINT), Random Gap Detection Test (RGDT, similar to GIN), filtered speech (FS) were significantly worse in the case of normal hearing subjects exposed to organic solvents as compared to not exposed individuals [26]. Further studies are needed to implement the temporal processing tests for occupational medicine purposes.

CONCLUSIONS

1. The reference ranges obtained in this study for the DPT and FPT in the Polish-speaking population are lower than the reference ranges previously published for speakers of other languages, which demands further investigation.
2. Normative values for the GIN obtained in this study are in accordance to those found in the literature.
3. Age, gender and ear symmetry did not influence the results of any of these tests.
4. Further studies are needed to implement the temporal processing tests for occupational medicine purposes.

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