The Journal of International Advanced Otology

J Int Adv Otol 2015; 11(2): 157-62 • DOI: 10.5152/iao.2015.809

Original Article

Wideband Tympanometry Normative Data for Turkish Young Adult Population

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OBJECTIVE: The aim of this study was to obtain norm values for a young adult Turkish group and to investigate the differences between female and male subjects in terms of wideband tympanometry.

MATERIALS and METHODS: One hundred ten young adult volunteers (mean±SD: 21.1±1.9 years) participated in this study. The measurements of wideband tympanometry were performed at octave frequencies between 226 Hz and 8000 Hz using Titan version 3.1. The stimulus level was set at 100 dB peSPL.

RESULTS: A cross-sectional study design was used. In total, 218 ears were tested. A significant relationship was found between gender and absorbance values for the frequency band from 3100 Hz to 6900 Hz. The difference between the middle ear resonance frequency and ear canal volume (ECV) of the male and female subjects was also found to be significant. The difference in ECV may result from the difference in body size between the male and female subjects because there was a significant relationship among ECV and the height and weight.

CONCLUSION: According to these results, it can be concluded that using separate norms for males and females may increase test specificity and sensitivity for the diagnosis of disorders, such as ossicular discontinuity and tympanic membrane perforations, affecting the high-frequency region.

KEYWORDS: Middle ear, wideband tympanometry, normative data, absorbance values, ear canal volume, resonance frequency, tympanometric peak pressure

INTRODUCTION

Wideband acoustic absorbance is used for research and clinical purposes. Wideband acoustic absorbance and reflectance measurements are used for testing normal middle ear functions [1], analyzing middle ear development [2, 3], measuring acoustic reflex [4], and evaluating the impact of pressure changes in the ear canal in middle ear function [3, 5].

Wideband immittance measurements provide objective data of the physiological structure of neonates to an adult's middle ear. In contrast to traditional immittance measurements, wideband immittance measurements can be measured between 226 Hz and 8 kHz.

There are previous studies about normalization in wideband tympanometry. The purpose of a norm is to determine the values for a specific population using a particular instrument and measurement. In this way, normal and diseased conditions can be determined in a more efficient way specific to that population. According to Turner et al. [6], the aim of any audiological test is to improve the sensitivity and specificity of the test. The main purpose of constituting a norm is to address the variability of different ethnic patterns such as weight, length, demographic characteristics, gender, and age, which can be dissimilar in different measurements [7, 8]. Clinicians usually use the same norms in the measurement using a wideband immittancemeter for the estimation of hearing thresholds despite ethnic differences [9, 10]. However, according to Shahnaz and Davies [8], this method can cause erroneous results. For example, Asians have a lower peak pressure, smaller ear canal, and broader tympanic cavity than Caucasians [9]. Despite this disadvantage of using the values obtained from an immittancemeter, knowing the average values of different groups can help evaluate people that have middle ear problems or hearing loss.

Another important point for constructing normative data relates to the age factor because maturation affects ear canal length and ossicle stiffness; for example, ear canal length and cavity increase with age, which influences the transfer of acoustic energy.

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Submitted: 30.12.2014 **Revision received:** 27.04.2015 **Accepted:** 28.04.2015

The purpose of this study was to construct normative data for wideband immittancemeter measurements and absorbance values of young Turkish adults.

MATERIALS and METHODS

The study was designed and performed according to the Declaration of Helsinki. After obtaining the approval of the local ethical committee and their informed consents, all volunteers underwent otoscopic examination, audiometry, wideband tympanometry, and transient evoked otoacoustic emission (TEOAE). The study group included 58 female and 51 male healthy volunteers. The descriptive statistics of the participant groups are given in Table 1.

All participants had a hearing threshold of better than 15 decibels (dB) between 250 Hz and 8000 Hz. They had less than 10 dB air–bone gap between 250 Hz and 4000 Hz. TEOAE was applied to all subjects. A ratio of emission to noise measuring more than 3 dB in the sub-octave frequency bands between 1000 Hz and 4000 Hz was treated as a pass for TEOAE. Volunteers who had tinnitus, middle ear or external ear canal pathologies, or a history of noise exposure were excluded. At the beginning of the study, the participants were asked about their ethnic origin, and if they had a Turkish origin, they were included in the study.

Pure-tone audiometry was conducted using AC-40 Clinical Audiometers (Interacoustic, Middelfart, Denmark). Measurements were taken in a soundproof room with TDH-39 (Telephonics, USA) earphones. Hearing thresholds were determined for octave frequencies between 0.125 kHz and 8 kHz.

Transient evoked otoacoustic emission tests were performed in a soundproof room using a Capella–Madsen adult OAE probe assembly (GN Otometrics A/S, Taastrup, Denmark) fitted to the ear canal. The fast-screen menu option was used. Responses to clicks were windowed at 3 to 20 ms after stimulus onset and were averaged following 2080 repeated responses. The used stimulus was a non-linear, 40 μs click. Clicks were presented at 80 dB sound pressure level (SPL).

To obtain tympanometric values, Interacoustics Titan version 3.1 (IMP440, Denmark) was used. Before the measurements, the wideband tympanometer was calibrated according to IEC 60645-5/ANSI S3.39, Type 1. The measurements of wideband tympanometry were performed at octave frequencies between 226 Hz and 8000 Hz and 100 dB peSPL (adult: 100 dB peSPL ≈ 65 dB nHL) in a silent room after calibration had been conducted by a clinician each day. The pressure was changed in the direction of positive to negative (+250 daPa to -400 daPa). The pressure change ratio was determined as 200 daPa/s. The absorbance; ear canal volume; resonance frequency (RESFREQ) of ear canal; and 226 Hz, 678 Hz, 1000 Hz, and averaged wideband frequency (375–2000 Hz mean) tympanometric peak pressure values were calculated and analyzed using a suitable probe tip (CIR 55-INSERT) placed external to the ear canal.

First, the normality of the absorbance, RESFRQ, compliance values, tympanometric peak pressure (TPP), gradient (tympanometric width), and ear canal volume (ECV) were tested by Shapiro–Wilk analysis and the distribution did not found as normal. Therefore, Mann–Whitney U test was performed using SPSS 13.0 for Windows (IBM Corporation, NY, USA) to test the statistical significance of these parameters. The value of $p \leq 0.05$ was considered to be significant. To find a correlation between the parameters, Spearman correlation analysis was performed using SPSS 13.0 for Windows. Spearman's rho correlation coefficient matrix for ECV, height, weight, RESFRQ, and TPP was computed and is given in the Results section. The value of Sigma (2-tailed) ≤0.05 was considered to be significant for the corresponding rho correlation coefficient.

Table 1. Descriptive statistics of the participants

PARAMETER	Gender	(n)	Mean±SD	Range
Height (cm)	Female	59	165.8±5.3	156–178
	Male	51	178.1±6.9	165–192
	Total	110	171.5±8.6	156–192
Weight (kg)	Female	59	60.0±10.1	45–92
	Male	51	75.4±10.1	60–100
	Total	110	67.2±12.1	45–100
Age (years)	Female	59	21.2±1.9	18.6–26.6
	Male	51	21.1±2	18.3–23
	Total	110	21.1±1.9	18.3–26.2

RESULTS

In total, the test values of 110 subjects were used in this study. The descriptive properties of the participants are given in Table 1. In total, 220 ears were tested in the second stage. However, two of the ears in the female subjects had middle ear problems and the results were therefore discarded. Therefore, 102 ears from the male subjects and 116 ears from the female subjects were used in the statistical analysis. The Mann–Whitney U test revealed that there was no significant relationship between tested ear and absorbance values for any frequency ($p>0.05$). Hence, descriptive statistics for absorbance values were computed over all ears.

Table 2 shows the results of absorbance values measured at ambient pressure for some selected frequencies. In the table, the mean, standard deviation, and 10 and 90 percentile of absorbance values for the male and female subjects are given. As shown from the table, the statistical analysis results showed a significant relationship between gender and absorbance values for a frequency band from 3100 Hz to 6900 Hz ($p<0.05$).

The mean absorbance values across the 250–8000 Hz frequency band for the male, female, and combined groups are given in Figure 1.

In this study, RESFRQ, compliance values, TPP, gradient, and ECV were also calculated for all subjects. Compliance, TPP, gradient, and ECV were calculated at the 226-Hz standard frequency used for the statistical analysis. The Mann–Whitney U test revealed that RESFRQ, compliance values, TPP, gradient, and ECV were not dependent on the tested ears ($p>0.05$). Hence, descriptive statistics for the tympanometric values were computed over all ears within the male and female subjects.

Table 3 shows a summary of RESFRQ, compliance values, TPP, and ECV normative data for male and female young Turkish adults. It can be

Table 2. Descriptive statistics and Mann–Whitney U test results of the absorbance at selected frequencies for male and female test subjects

	FEMALE			MALE			COMBINED				Sigma
Freq. (Hz)	Mean±SD	10%	90%	Mean±SD	10%	90%	Mean±SD	10%	90%	Z	(2-tailed)
226	0.12±0.05	0.05	0.19	0.13±0.05	0.06	0.19	0.12±0.05	0.06	0.19	-1.831	0.067
324	0.14±0.07	0.05	0.24	0.16±0.07	0.07	0.25	0.15±0.07	0.06	0.24	-1.993	0.046
385	0.18±0.08	0.07	0.29	0.20±0.08	0.09	0.3	0.19±0.09	0.08	0.30	-1.945	0.052
500	0.27±0.11	0.13	0.40	0.29±0.01	0.15	0.42	0.28±0.11	0.15	0.41	-1.244	0.214
629	0.38±0.16	0.20	0.58	0.37±0.12	0.20	0.52	0.37±0.13	0.20	0.55	-0.211	0.833
793	0.53±0.16	0.34	0.76	0.52±0.14	0.35	0.72	0.52±0.15	0.35	0.73	-0.850	0.395
1000	0.67±0.14	0.48	0.85	0.65±0.14	0.45	0.83	0.66±0.14	0.48	0.84	-1.077	0.281
1259	0.69±0.13	0.48	0.84	0.67±0.14	0.46	0.83	0.68±0.14	0.47	0.84	-1.310	0.190
1587	0.67±0.14	0.48	0.84	0.66±0.14	0.44	0.83	0.67±0.14	0.45	0.83	-0.826	0.409
2000	0.68±0.14	0.49	0.89	0.69±0.16	0.42	0.88	0.68±0.15	0.47	0.88	-0.745	0.457
2519	0.72±0.16	0.50	0.95	0.71±0.17	0.42	0.92	0.72±0.17	0.49	0.92	-0.400	0.689
3174	0.73±0.19	0.46	0.96	0.69±0.18	0.40	0.90	0.71±0.18	0.44	0.93	-2.149	0.032
4000	0.66±0.20	0.37	0.89	0.60±0.16	0.34	0.81	0.64±0.18	0.36	0.86	-3.270	0.001
5039	0.54±0.18	0.31	0.78	0.42±0.14	0.28	0.58	0.49±0.17	0.32	0.73	-5.766	0.000
6349	0.46±0.14	0.28	0.64	0.40±0.14	0.27	0.6	0.44±0.13	0.28	0.62	-3.351	0.001
8000	0.30±0.20	0.09	0.54	0.34±0.28	0.06	0.76	0.33±0.24	0.08	0.72	-0.027	0.979

Freq.: measurement frequency; SD: standard deviation

Table 3. Descriptive statistics and Mann–Whitney U test results of RESFRQ, compliance values, TPP, and ECV for male and female test subjects

	RESFRQ (Hz)	Compliance (ml)	TPP (daPa)	ECV (cc)	Gradient (daPa)
Gender	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Male	933±250.21	0.57±0.24	-0.57±24.89	1.16±0.27	95.26±31.40
Female	992.45±215.97	0.51±0.19	-8.58±13.82	0.93±0.23	95.93±31.14
Overall	964.66±233.94	0.54±0.21	-6.71±19.84	1.04±0.27	95.61±31.19
Z	-2.04443	-0.80908	-0.05923	-5.93967	-0.24968
Sigma (2-tailed)	0.040911	0.418467	0.952767	0.000001	0.802835

RESFRQ: resonance frequency; TPP: tympanometric peak pressure; ECV: ear canal volume; SD: standard deviation

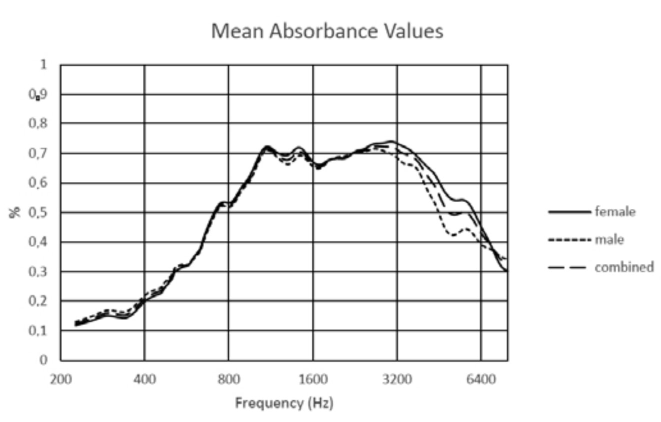

Figure 1. Mean absorbance values of the male and female subjects

seen from the table that there was significant difference in ECV and RESFRQ for the male and female subjects [Sigma (2-tailed) <0.05)].

The Spearman correlation analysis results are given in Table 4. It is shown in the table that there is a significant correlation between ECV, height, and weight. Because the height and weight also define also the body size of people, it can be concluded that ECV has a significant correlation with body size. From the results given in the table, it can also be stated that there was a significant correlation between TPP and RESFRQ. However, the analysis did not show any relationship between RESFRQ and body size. The same result was also obtained for TPP and body size.

DISCUSSION

The results of the studies showed that absorbance values were significantly different among different ethnic and age groups. There-

Table 4. Spearman's rho correlation coefficient matrix for ECV, height, weight, RESFRQ, and TPP

Parameter		ECV	HEIGHT	WEIGHT	RESFRQ	TPP
ECV	Rho	1	0.27	0.30	-0.10	0.04
	p values	NA	0.00001	0.000001	0.12	0.49
	N	218	218	218	218	218
HEIGHT	Rho	0.27	1	0.69	-0.10	0.007
	p values	0.00001	NA	0.000001	0.13	0.90
	N	218	218	218	218	218
WEIGHT	Rho	0.30	0.69	1	-0.10	0.04
	p values	0.000001	0.000001	NA	0.10	0.47
	N	218	218	218	218	218
RESFRQ	Rho	-0.10	-0.10	-0.10	1	-0.19
	p values	0.12	0.13	0.10	NA	0.004
	N	218	218	218	218	218
TPP	Rho	0.04	0.0079	0.04	-0.19	1
	p values	0.49	0.90	0.47	0.004	NA
	N	218	218	218	218	218

RESFRQ: resonance frequency; TPP: tympanometric peak pressure; ECV: ear canal volume

fore, obtaining norms for different groups and the use of these norms should result in more accurate wideband tympanometric measurements.

The aim of this study was to obtain norm values for Turkish young adults and to investigate differences between male and female subjects in terms of wideband tympanometry. The observed differences are given in the following paragraphs.

In this study, a significant relationship was found between gender and the absorbance values for a frequency band from 3100 Hz to 6900 Hz. The same results were also reported in the literature. Shahnaz et al. [7] reported that reflectance varies differently between females and males across different frequencies. They used a Mimosa Acoustics system to collect data. Their analysis showed that the relation between gender and reflectance values was significant. The male subjects had a higher reflectance between 4000 Hz and 5000 Hz. Similarly, Kenny [10] stated that the correlation between gender and absorbance values was significant. He obtained absorbance values at an ambient pressure level. His results indicated that the variation of absorbance across frequency changed differently between groups. This result demonstrated that the overall dynamic power absorbance differed between Caucasian males, Caucasian females, Chinese males, and Chinese females. Similarly, in our study, females also differed significantly from males at high frequencies. As seen in Figure 1, the female subjects showed a higher absorbance than the male subjects.

In this study, statistical analysis showed that body size was significantly different between the male and female subjects ($p<0.005$). This may be a cause for the high absorbance values in the female subjects at higher frequencies. Similarly, in literature, it was stated that higher absorbance values in the female subjects might be the result of body size differences [8, 9]. In the study by Shahnaz and Borg [9], there were 62 Caucasian participants and 64 Chinese participants. The ages of the participants were between 18 and 32 years. The researchers measured wideband energy reflectance using Mimosa Acoustics RMS system. The results of this study showed that Chinese subjects had lower reflectance values between 3891 Hz and 6000 Hz. They also measured lower admittance values for the Chinese subjects than for the Caucasian subjects between 211 Hz and 1313 Hz. This difference was found to be statistically significant. They also found that female subjects had significantly lower admittance values than male subjects between 1781 Hz and 2367 Hz. In this study, it was stated that the Chinese have a smaller body size than Caucasians and that differences in the results might be due to body size differences in the two groups.

In addition, in animal studies, it was revealed that the size of some middle ear anatomic parts is closely related to body size [11, 12]. For example, the area of the tympanic membrane, volume of the middle ear cavity, and area of the stapes footplate change with body size. Huang et al. [11] stated that there is a close relationship between body size and smaller middle ear compliance in animals. This implies that differences in the body size of the male and female subjects in our study may provide indirect evidence of middle ear size involvement in the measured wideband absorbance values.

It can be seen from Table 3 that there is a significant difference in RESFRQ of the male and female subjects. In literature, the results of multifrequency tympanometry showing the effect of gender on RESFRQ are not certain. Although Hunter et al. [13, 14] stated a higher value for the resonant frequency for males than females, Wiley et al. [15, 16] reported lower resonant frequency values for males than females. Similarly, Shahnaz and Davies [8] did not find any statistical difference between males and females for resonant frequency in either Caucasian or Chinese subjects. However, they reported that the Chinese subjects showed a higher mean RESFRQ than the Caucasian subjects and that this difference was found to be statistically significant. They stated that this higher RESFRQ was the result of increased stiffness in the middle ear transmission system of the Chinese subjects. Additionally, they measured significantly higher mean static admittance values in Chinese males than in Chinese females. These results were also consistent with those of Roup et al. [17] Although the trend in the findings of Wan and Wong [18] was the same, they did not report any significant gender differences in young Chines adults. In our study, the compliance values were measured. It can be shown from Table 3 that the male subjects showed slightly higher compliance values than the female subjects. However, this difference was not found to be significant. Therefore, the difference in RESFRQ between the male and female subjects might be the result of differences in compliance values.

It can be seen from Table 3 that there is a significant difference in ECV of the male and female subjects. Males have higher ECV than females. The different body size of the subjects (males and females) may be the reason for this difference. Similar results were also reported in literature. Shahnaz and Davies [8] reported that gender is a significant factor for ECV because males had significantly higher ECV than females. They also reported that Chinese subjects had significantly lower ECV values than Caucasian subjects. To compensate for the effect of body size, they statistically compared the values of Chinese male subjects with Caucasian female subjects, assuming that female subjects on average have a smaller body size than males. Therefore, they compared two subgroups having similar body size. They found ECV to be 1.10 for the Caucasian females and 1.05 for the Chinese males. In this analysis, they did not find any significant difference between the two subgroups. These results are also consistent with the results found by Shahnaz and Bork [9], Wan and Wong [18], and Roup et al. [17]

Shahnaz and Davies [8] performed a univariate analysis of variance to examine the effect of gender on ECV, TPP, tympanometric width (TW), and static absorbance (SA). They found that the effect of gender was not significant for TPP, TW, and SA. However, they stated that females show significantly lower ECV than males. In the same study, they reported that TPP for the Chinese subjects was -0.6 daPa, while it was-5.08 daPa for the Caucasian subjects. This meant that the Chinese subjects had more positive TPP than the Caucasian subjects. These results are also similar to the results reported by Wan and Wong [18]. They used standard 226-Hz tympanometry for comparison and did not find a significant difference in SA, TW, and TPP between males and females. On the contrary, it was stated in Roup et al. [17] and Wiley et al. [15] that the male subjects had a larger mean SA than the female subjects. The different results from study to study might be due to different procedures followed. However, each study used the same procedure for the male and female subjects within an individual study.

Compliance value, TPP, and gradient were measured in our study. The statistical analysis results are given in Table 3. It can be concluded from Table 3 that although the female subjects has a lower compliance and more negative TPP, the differences are not significant. These results are similar to those reported by Shahnaz and Davis [8], Wan and Wong [18], and Margolis et al. [19]

The Spearman correlation analysis results are given in Table 4. The results show that there is a significant relationship between TPP and RESFRQ. The more negative TPP shows that stiffness in the middle ear is increased, causing a decrease in compliance values. Similarly, due to the low the compliance values, the mean resonance value of the female subjects is also higher than that of the male subjects.

It can be seen from Table 4 that there is a strong correlation between body size and ECV. This may be expected as an increase in body size can result in an increase in the circumference of the head and an increase in the ear canal size. Similar results have also been reported in literature.

The aim of any audiological test is to improve the sensitivity and specificity. This can be achieved in three different ways. The first way is to modify the threshold level. The second way is to use norms specific to the test instruments, and the last way is to use norms specific to the population.

A tight criterion will cause better test specificity and worse sensitivity because less healthy ears will be mistakenly diagnosed as being disordered (smaller amount of wrong alarms), but less of the disordered ears will be identified (more failure to catch). In the meantime, a loose criterion would result in a worse test specificity and better test sensitivity because extra healthy ears will be incorrectly diagnosed as being disordered (more wrong alarms) and extra disordered ears will be recognized as being disordered (more hits). Therefore, the criterion should be optimized to increase specificity or sensitivity according to the population that is being tested [6]. Shahnaz and Bork [9] reported that the use of instrument-specific norms did not result in improved sensitivity and specificity. However, there are some studies that report increased sensitivity and specificity using population-specific norms [20, 21, 22].

In this study, significant differences in ECV, RESFRQ, and absorbance for the high-frequency region were found between the male and female subjects. The significant ECV differences found between the male and female subjects may improve the procedure for the diagnosis of tympanic membrane perforations or in assessments for pressure equalization tubes. The result of this study showed that body size plays a crucial factor in the observed differences between the male and female subjects at the standard probe tone frequency of 226 Hz. Other mechano-acoustic properties of the middle ear may contribute to differences in the absorbance at higher probe tone frequencies.

In this study, the tympanometric norm values for the young adult Turkish subjects were obtained, and differences between the female and male subjects in terms of wideband tympanometry were investigated. The results showed a significant relationship between gender and absorbance for a frequency band from 3100 Hz to 6900 Hz. According to these results, it can be concluded that using separate norms for males and females may increase test specificity and sensitivity for the diagnosis of disorders, such as ossicular discontinuity and tympanic membrane perforations, affecting the high-frequency region. In other cases, the use of a combined norm may be more suitable because the use of separate norms would not improve test specificity and sensitivity. Hence, from the results of this paper, it can be concluded that different norms for male and female young adults may have a diagnostic value. However, the pros and cons of implementing separate norms should also be taken into account.

Ethics Committee Approval: Ethics committee approval was received for this study from institutional ethics committee.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - Z.P.; Design - Z.P.; Supervision - Z.P., A.A.; Materials - B.B.; Data Collection and/or Processing - B.B., D.H., E.B; Analysis and/or Interpretation - Z.P.; Literature Review - B.B., D.H., E.B.; Writing - Z.P., B.B., E.B.; Critical Review - Z.P., A.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

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