Hearing Threshold in Audiometry Testing: Pure Tone Versus Warble Tone.

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Abstract:

Background: It has long been debated among audiologists whether pure tone and warble tone can be used interchangeably in clinical settings to quantify the amount of hearing threshold. The disputes on this issue inspired this study to investigate the differences in hearing threshold between pure tone and warble tone in audiometry testing.

Materials and Methods: Audiometric test was conducted on 20 normal hearing adults (40 ears) at six frequencies at octave intervals from 250 Hz to 8000 Hz with three different stimuli presentation; (i) pure-tone stimulus (PT); (ii) warble tone stimulus presented for 2-3second (WT3); and. (iii) warble tone stimulus presented for 4 seconds and more (WT4).

Result: This study found that WT4 elicited the lowest threshold as compared to the other two stimulus presentation: PT and WT3. No significant differences observed between PT and WT3 thresholds. There were significant differences between PT and WT4 at all frequencies except for 250 Hz and 8000 Hz; as well as between WT3 and WT4 at all frequencies except for 2000 Hz and 8000 Hz. However, all differences were not clinically significant.

Conclusion: These findings support the notion that warble tone can be used to measure thresholds since the substitutions did not violate the 5-dB step size in clinical application.

Keywords: Pure tone, warble tone, pure tone audiometry, hearing thresholds

Introduction:

Until recently, tuning fork was used to determine whether the hearing loss is conductive or sensorineural. However, tuning fork does not provide calibrated signal as audiometer in which, the signal intensity and duration could be controlled by the tester (Katz, 2015). Nowadays, pure tone audiometry test has become the gold standard test for hearing loss diagnosis and becoming one of the tests that have been used clinically to quantify one's hearing sensitivity for calibrated pure tones (American Speech-Language Hearing Association, 2005). Pure tone audiometry yields the diagnostic information about the different channels' integrity in the neural pathway for the quantification of hearing threshold (Katz, 2015). Thus, PT threshold is described as the lowest level of response to tonal stimulus or also known as the lowest intensity that could be heard 50% of the time and is used as reference level for suprathreshold speech test presentation alongside establishing the hearing aid and cochlear implant candidacy (Katz, 2015).

During standard audiological procedures for hearing assessment PT stimulus is presented through headphones. However, when headphones cannot be used, the sound field is used as the alternative in replacing the transducers especially when testing paediatrics and aided evaluation of hearing aids. There have been arguments on the usage of PT stimulus for sound field testing. First, the nature of the PT is uninteresting when used in paediatric population (Orchik, 1973), and second, the effect of standing waves which can alter the PT signal intensity (Kutz, Mullin & Campbell, 2012). To overcome this issue, warble tone (WT) and narrow band noise (NBN) was frequently being used to substitutes pure tone (PT) especially in paediatric testing (Bender, 1967; Dockum, 1975), patients with significant tinnitus (Alpiner, 1968; Dockum, 1975; and sound field testing (Reilly, 1958; Dockum, 1975; Kutz et al., 2012). Despite being labelled as attention-getting and easier to listen to properties similarly to WT (Kutz et al., 2012), previous findings shown that NBN overestimate PT threshold by 20 to 30 dB at mid-range frequencies (Orchik & Mosher, 1975; Kutz et al., 2012) making it less suitable to be used as PT substitutes especially for sound field testing. On the other hand, significant agreement was found between PT and WT (Staab & Rintelmann, 1972; Dockum & Robinson, 1975; Kutz et al., 2012). However, the evidence to support the idea that WT and PT are comparable to each other in terms of seeking hearing threshold especially through transducers remains limited.

In play audiometry, 120 dB WT will be presented through the headphone on the table during conditioning (IIUM Hearing & Speech Protocol, 2006). Some of the audiologists will switch to PT when testing with the headphone on the child's head for separate ear measurement, in which could lead to confusion for children and patients with intellectual disability to respond to the stimuli as they have different psychoacoustic nature. Considering that some audiologists choose to maintain to use warble tone even though they are testing using transducers. This situation however has created a debatable argument whether it is appropriate to use warble tones with transducers or change into pure tones whenever a separate ear measurement is conducted as the hearing threshold would be better when tested with WT (Franklin, Franklin, & Franklin, 2011). Additionally, more information needed on the duration of the WT to be presented for the stimulus to be adequate to be perceived by the auditory nerves. Therefore, it is important to find out whether the hearing threshold remains the same between WT and PT stimulus during audiometry testing using transducers, and whether the presentation duration of WT stimulus could affect hearing threshold level.

Materials and Methods:

A cross-sectional study was conducted to find the difference in hearing threshold between PT and WT in audiometry testing among normal hearing adults. This study was conducted in a calibrated and soundproofed room at International Islamic University Malaysia (IIUM) Hearing and Speech Clinic, Jalan Hospital Campus, Kuantan, Malaysia. This research has been reviewed and approved by the IIUM Research Ethics Committee (IREC). All subjects' details and information were kept confidential.

Normal hearing participants ranging from 18 to 25 years old with a mean of 23 years old were recruited among students of IIUM, Kuantan Campus, Pahang. Requirements for the designation normal hearing were; no previous history of otological problems, no constant and disturbing tinnitus and hearing at least as good as 20 dB HL. Participants who have experienced tinnitus for more than 5 minutes and has a history of chronic illness has been provided with proper management.

Convenience sampling technique was used in this study to approach subjects. The sample size was calculated using PS Power and Sample Size based on the mean and standard deviation from Arlinger and Jerlvall (1987). Hence, in this study, 20 participants were recruited regardless of their gender.

The ethical approval was obtained from IIUM Research Ethics Committee (IREC). The reference number for the ethical approval is

IIUM/310/G/13/4/4. Research information and consent form sheet was given to the participants before testing. Verbal and written consent were obtained once the subject agreed to the terms and conditions.

Full history taking was taken before the test is conducted. The participants were asked with questions regarding general health, hearing problems, otological problem, tinnitus, vertigo, noise exposure, head and neck injury and medical history.

Prior to the test, otoscopic examination was done to examine the external auditory canal and tympanic membrane visually to rule out any deformities, conductive element in the outer ear, or collapsing ear canal. During this examination, pinna was pulled posterior-superiorly to straighten the cartilaginous portion of the ear canal to view the tympanic membrane. The collapsing ear canal was checked by looking at the mobility of ear canal walls by pushing the pinna towards head to mimic headphone pressure on the pinna and tragus.

The immittance testing was conducted using Grason Stadler Tympstar Middle Ear Analyzer to rule out any middle ear problem. The proper probe size was chosen depending on the size of the ear canal to obtain good seal and accurate reading. Tympanogram types alongside the ear canal volume (ECV), static compliance (SC) and pressure (da Pa) was noted. Only participants with type A tympanogram are included in the study.

Hearing thresholds were obtained using an Interacoustics audiometer AD 226 with circumaural headphones calibrated with American National Standards Institute specification (American National Standards Institute, 2004). Modified Hughson-Westlake methods with 10-dB down, 1-dB up was used for threshold seeking of subjects using pure-tone and WTstimulus at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000Hz and 8000 Hz. When testing with pure-tone, the stimulus was presented for 200 to 300-ms duration. A short break between 5 to 10 minutes was given upon completion of the pure-tone testing before proceeding with the WT testing. The WT were frequency-modulated tones modulated at 5 HZ with a ±5% modulation depth (Lentz, Walker, Short & Skinner, 2017). The WT stimulus were also presented within 200 to 300-ms. The results were recorded in audiogram.

Result:

A total of 20 normal hearing adult subjects was recruited in this study. The age range of the subjects was 20 to 25 years old. Data was collected from both ears for each subject. Hence, the total ears obtained was 40 ears. Table 3.1 recorded the mean and SD of hearing threshold level of each stimulus used for frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000Hz and 8000 Hz.

Table 3.1 Hearing Threshold level's mean and standard deviation for PT, WT3 & WT4

Frequency (Hz)	*Tone [Mean (SD)]*		
	PT	WT3	WT4
250	4.85 (4.8)	5.90 (4.21)	3.43 (5.35)
500	7.10 (4.44)	8.25 (4.05)	4.70 (5.37)
1000	5.67 (3.65)	5.48 (3.54)	3.40 (3.99)
2000	4.88 (5.35)	2.88 (5.12)	1.18 (5.99)
4000	3.05 (4.56)	3.23 (3.38)	0.88 (3.50)
8000	-6.13 (4.48)	-6.98 (4.16)	-7.35 (3.72)

The means for 250 Hz are 4.85, 5.9 and 3.43 for PT, WT3, and WT4, respectively. The standard deviation for 250 Hz threshold ranges from 4.21 to 5.35. The lowest value of mean in 500 Hz is 4.7, which is for WT4. This is followed by PT and WT3, which is 7.1 and 8.25. Next, the standard deviations are 4.44, 4.05 and 5.37 for PT, WT3, and WT4, respectively. 1000 Hz and 2000 Hz show the same trend for mean, where the highest mean value is for PT and followed WT3 and WT4. For 1000 Hz, the means are 5.67, 5.48 and 3.4 while the mean for 2000 Hz are 4.88, 2.88 and 1.18. Besides, the standard deviation of 1000 Hz ranges from 3.54 to 3.99 while for 2000 Hz, it ranges 5.12 to 5.99. For 4000 Hz, the means in these three tones ranged from 0.88 to 3.23. Furthermore, the standard deviations for PT, WT3, and WT4 are 4.56, 3.38 and 3.5, respectively. Lastly, 8000 Hz has the lowest means compared to other frequencies which are -6.13, -6.98 and -7.35 for respective PT, WT3, and WT4. For standard deviation, it ranges from 3.72 to 4.48.

To sum up, the means in all frequencies WT4 has consistently better thresholds compared to PT and WT3. WT3 constantly has the smallest standard deviation except for 8000 Hz while the PT has highest standard deviation throughout the frequencies except for 4000 Hz and 8000 Hz. The trend of threshold for PT and WT4 are similar where the thresholds are gradually better from the lowest frequency to the highest frequency, except for 250 Hz. In overall, 250 Hz seems to have a better threshold compared to the adjacent frequency, 500 Hz. For 8000 Hz, it has the lowest threshold for all three tones and the threshold is slightly getting better from PT, WT3 to WT4.

One of the primary questions about this work was to establish whether significant differences on hearing threshold level existed between different stimuli; PT, WT3 and WT4 in normal hearing adults.

The types of stimulus are considered as independent variables since they were unrelated to each other. Hence, independent t-test is used to compare whether the difference is attributable to a chance between; (i) PT and WT3; (ii) PT and WT4; and, (iii) WT3 and WT4. The results as in table 3.2.

Table 3.2 Mean of Differences in Hearing Threshold Level between stimulus used in 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000Hz and 8000 Hz.

Frequency (Hz)	Stimulus	Stimulus	T	Sig.
250	PT	WT3	-1.040	0.302
	WT3	WT4	2.298	0.024
	WT4	PT	1.253	0.214
500	PT	WT3	-1.211	0.230
	WT3	WT4	3.339	0.001
	WT4	PT	2.179	0.032
1000	PT	WT3	0.249	0.804
	WT3	WT4	2.463	0.016
	WT4	PT	2.663	0.009
2000	PT	WT3	1.709	0.091
	WT3	WT4	1.443	0.153
	WT4	PT	2.913	0.005
4000	PT	WT3	-0.195	0.846
	WT3	WT4	3.005	0.004
	WT4	PT	2.395	0.019
8000	PT	WT3	0.879	0.382
	WT3	WT4	0.425	0.672
	WT4	PT	1.331	0.187

No significant difference in hearing threshold level were found between PT and WT3 in all frequencies tested ($p>0.05$). However, significant difference was evidence between hearing threshold level in PT and WT4 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz while no significant difference found at 250 Hz and 8000 Hz.
Figure 1: Level of knowledge amongst respondents

Discussion:

The thresholds for PT and WT were compared because both tones are typically used in audiology clinic with the environmental noise level calibrated according to ANSI S3.1-1999. It was hypothesized that the differences in the measured thresholds would not be statistically or clinically different.

The threshold elicited by WT4 stimulus shown consistently better level as compared to PT and WT3 in all frequencies tested. This is due to the facts that sensory and perceptual processing is quicker in more intense physical stimuli, subsequently leads to fast reaction time. (Kohfeld, 1971, Levick, 1973). The auditory system uses short time constant windows at the acoustic input. The longer presentation time, which in this case 300 to 400-ms for WT4 causing the auditory system to accumulate information from each window for detection and eventually leads to improved threshold (Viemeister & Wakefield, 1991).

Evidently, no significant difference in hearing threshold level between PT and WT3 were found in this study in 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000Hz and 8000 Hz. This finding was consistent with past research which reported that using either PT or WT would not affect hearing threshold (Dockum & Robinson, 1975; Orchik & Rintelmann, 1978; Franklin et al., 2009). However, to date, the research comparing the presentation duration stimulus in WT stimulus remained scant.

WT4 was found to be significantly better than WT3, except at 2000 Hz and 8000 Hz. Similarly, Hamill & Haas (1986) reported lower audiometric thresholds for warble tones over pure tones in the extended high frequencies and consequently cautioned against using warble tones for high-frequency audiometry. This is because, it was suggested that the difference in hearing threshold level might depends on the modulation rate and the size of the frequency deviation (Hamill & Haas, 1986). However, despite being statistically significant in research application, the difference was around 0.2 to 3.7 dB, which is less than 5 dB, suggesting that the size of the threshold difference was not clinically significant as in clinical settings the 10 dB-down, 5 dB-up method was used. This is further supported by Dockum & Robinson (1975) and Franklin et al. (2009) who performed similar studies and reported comparable findings. Therefore, the consistencies of data reported exhibit further evidence that there was no significant difference in threshold between PT and WT.

In conclusion, the measured results, taken together with previous findings (Dockum & Robinson, 1975; Orchik & Rintelmann, 1978; Mineau & Schlauch, 1997; Burk & Wiley, 2004; Franklin et al., 2009), support the ASHA (2005) guidelines in substituting WT over PT in PTA since the differences of thresholds are not more than 5 dB, as suggested clinically. However, in choosing a stimulus, different types of stimulus such as pulsatile tone, PT and WT may be more effective for listeners with different underlying issues such as tinnitus (ASHA, 2005).

One of the limitations of this study is limited time for data collection. This is due to the recovery movement control order (RMCO) commanded by the government to control the pandemic of Covid-19. Due to this unfortunate event, further testing on more participants could not be proceeded.

Even though PT and WT can be used interchangeably according to this study, further testing at interoctave frequencies (3000 Hz and 6000 Hz) as well as extended-high frequencies also needs to be done as these frequencies are also included in the guidelines of ASHA (2005). Further study on paediatric population and population with hearing loss also need to be performed to recommend the substitution of one tone over the other in the future.

Conclusion:

In conclusion, this study supports the use of WT stimulus for PT stimulus substitution in measuring hearing threshold as recommended by ASHA (2005). However, further research needs to be done to gauge whether or when these disparities become statistically or clinically significant.

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