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Effect of Striking Styles and Placement Angle on the Acoustic Characteristics of Tuning Forks

Tınlatma Biçimleri ve Tutma Açısının Diyapozonların Akustik Özellikleri Üzerindeki Etkisi

Süleyman BOYNUEĞRİ[a], Mustafa YÜKSEL[b], Yusuf Kemal KEMALOĞLU[c]

[a]Department of Otorhinolaryngology, Numune Education and Research Hospital of Ankara, Ankara, TURKEY
[b]Department of Speech and Language Therapy, Ankara Medipol University Faculty of Health Sciences, Ankara, TURKEY
[c]Department of Otorhinolaryngology, Gazi University Faculty of Medicine, Ankara, TURKEY

This study has been partially presented in in the 13th Congress of European Federation of Audiology Societies, June 7-10, 2017, Interlaken, Switzerland.

ABSTRACT Objective: Tuning forks (TFs) are still a valuable tool for physicians to evaluate the hearing of subjects before referring for audiological assessment. However, there have been some controversial data about the accuracy of TF tests in relation to the air-bone gap in pure tone testing. It is possible that differences in striking and holding styles might have an effect on this discrepancy. Therefore, the aim of this study was to compare striking styles and placement angles of TFs. **Material and Methods:** C2- and C3-TFs were tuned by 15 physicians by both pisiform bone strike (PBS) and pinch with fingers (PwF). After being struck, the TFs have held 3 cm away from a microphone in parallel (PA) and perpendicular (PE) placement. Fundamental frequency and first and second overtones and their decay times were analyzed. **Results:** Although fundamental frequency was not statistically different between PBS and PwF, decay time of C2-TF was significantly longer by PwF (70,94 s) than by PBS (67,42 s). Further, it was found that fundamental frequencies with PA placement were higher than those with PE placement. The difference between placements for C2-TF was statistically significant. No difference was found in fundamental frequency decay time for C2-TF between PE and PA placement, while fundamental frequency decay time for C3-TF was statistically longer in PA placement. **Conclusion:** This study shows that placing the TFs against the ear at a PE angle shortens the sound duration. That difference could result in a negative Rinne test, even if the air-bone gap on the audiogram is not much larger. If the use of the Rinne test for case selection for stapes surgery is recommended, following the classic recommendations for TF use (PBS-PA) appears to be important.

Keywords: Acoustics; bone conduction; conductive hearing loss; hearing tests; audiology

ÖZET Amaç: Diyapozonlar, hastaların odyoloji birimlerine yönlendirilmeden önce işitmesinin değerlendirilmesinde hekimler tarafından hâlen kullanılan önemli bir araçtır. Ancak, diyapozon testlerinin saf ses odyometri testinde gözlenen hava-kemik aralıklarını tespit etme başarıları hakkında literatürde tutarsız bulgular bulunmaktadır. Tınlatma ve tutma biçimlerinin söz konusu tutarsızlık üzerinde etkisi olması mümkündür. Bu nedenle çalışmamızın amacı, diyapozonların vurma ve tutma biçimlerini karşılaştırmaktır. **Gereç ve Yöntemler:** C2 ve C3 diyapozonlar 15 hekim tarafından pisiform vuruş (PV) ve parmakla çekme (PÇ) yöntemleriyle titreştirilmiştir. Ardından, diyapozonlar mikrofondan 3 cm uzaklıkta yan ve dik olarak tutulmuştur. Temel frekans, birinci ve ikinci üst tonlar ile bunların sönme zamanları analiz edilmiştir. **Bulgular:** Her ne kadar PV ve PÇ arasında temel frekans açısından elde edilen farklar istatistiksel olarak anlamlı olmasa da C2 diyapozonun PÇ ile sönme zamanının PV'ye göre istatistiksel olarak daha uzun süre aldığı gözlenmiştir. Dahası, yan tutuşta temel frekansın dik tutuşa göre daha yüksek olduğu görülmüş ve C2 diyapozon için elde edilen farklar istatistiksel olarak anlamlıdır. Temel frekansın sönme zamanı açısından C2 diyapozonda yan ve dik tutuş arasında fark elde edilemezken, C3 diyapozonda yan tutuşta elde edilen sönme zamanı istatistiksel olarak anlamlı derecede uzundu. **Sonuç:** Çalışmamız, diyapozonu kulağa dik tutmanın uyaran süresini kısalttığını göstermiştir. Bu durum, odyogramda hava-kemik aralığının gözlenmesine rağmen Rinne testinde negatif sonuç alınmasına yol açabilir. Eğer stapes cerrahisi kararında Rinne testinin sonuçları da göz önüne alınacaksa, diyapozonu klasik öneride de olduğu gibi PV yöntemiyle yan tutmak daha doğru bir sonuç elde edilmesini sağlayacaktır.

Anahtar Kelimeler: Akustik; kemik iletimi; iletim tipi işitme kaybı; işitme testleri; odyoloji

Tests using tuning forks (TFs), particularly Weber and Rinne tests, are still recommended as a routine part of otolaryngological examination. The effectiveness of negative Rinne test in separatingfar-advanced otosclerosis from sensorineural hearing loss of other causes has been demonstrated byShea, Ge

Correspondence: Mustafa YÜKSEL
Department of Speech and Language Therapy, Ankara Medipol University Faculty of Health Sciences, Ankara, TURKEY/TÜRKİYE
E-mail: mustafa.yuksel@ankaramedipol.edu.tr

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and Shea.[1] House and Cunningham point out that most surgeons consider a positive Rinne as an absolute contraindication to surgery for otosclerosis.[2] Furthermore, although bone vibrators are the standard and most common tools for the evaluation of bone conduction in audiology, it has been argued that as a result of higher peak intensity,bone conduction by TFs has an advantage over bone vibrators for cochlear implant candidates.[3] However, as Kelly, Bin and Adams suggested in their study, there is a substantial variability in reported accuracy of TF tests in the literature and optimal TF test procedures are needed to improve and stabilize the accuracy of TF tests.[4]

Proper use and material properties of TFs have been the subject of various research.[1,3,5,6] Although the TFs used today are composed of aluminum, it has been shown that they were not as useful as steel TFs in detecting a smaller air-bone gap, and thealuminum TFs (particularly C2-TFs) loset heir physical properties because of metal fatigue overtime.[5] As a result, their fundamental frequency and decay times show differences up to approximately 74% and 41%, respectively.[7] Besides, Butskiy, Ng, Hodgson and Nunez published objective data supporting the classic recommendation about placingthe TFs parallel (PA) to the external ear canal (through the vibrating tinesof the fork), compared with the perpendicular (PE) placement.[8,9] They found that PA placement results in a higher sound energy at the level of the tympanic membrane. In earlier research, it was suggested that striking styles result in different acoustical properties for C1- and C2-TFs, but not for C2- and C3-TFs.[10] Stevens and Pfannenstiel noted the importance ofthe striking surface characteristics and reported the presence of additional non fundamental sound frequencies produced secondary to striking a TF off a metal or wooden material instead of the human palm.[11] This additional sound energy could affect clinical testingand complicate decisions regarding surgical candidacy.Watson also recommended the use of pisiform bone strike (PBS).[12] These data validate theimportance of the classic textbook recommendation that TFs should be vibrated by pisiform bone and then listened to by the subject through the vibrating tines of the TF (parallel to the external ear canal).[9]

Another striking or tinning style is pinching the TF between two fingers (PwF) as shown in Figure 1a. PwF produces sound not by striking one of the forks to any surface, but by pulling them to each other concurrently ("pinch"). That is, the sound via PwF is produced by the opposite action of the tines through the vibration in contrast to the parallel action of the tines when one of the tines is struck to either hard or soft material. Hence, the opposite action of the tines may affect the frequency of the generated sound. This is a very common practice in Turkey and there are not any published data about methods of pinching TFs. Hence, in this study, these two different tinning styles were compared, PBSor PwF. In addition, two different placement orientations, parallel (PA) or perpendicular (PE) to the external ear canal, were analyzed.

MATERIAL AND METHODS

This study was performed with 15 physicians, working in the otolaryngology departments (seniors and residents) to get average values for different striking and placement styles. Both C2-TF (512 Hz) and C3-TF (1024 Hz) were used. Both TFs were manufactured by Karl Storz (Karl Storz SE & Co. KG, Tuttlingen, Germany) and unused prior to this research. Since no experiments were conducted on human or animal subjects, no ethical committee approval or informed consent wasneeded.

The samephysicians tuned two different TFs for three different conditions: PwF (Figure 1a) with PA (Figure 1b) position of TFs to microphone;PBS (Figure 1c)with PA (Figure 1b) position of TF to microphone; PBS (Figure 1c) with PEposition (Figure 1d) of TF to microphone.Therefore, each physician struck TFs six times.

Sound samples of TFs were recorded directly into the Praat sound analysis software using a 44000-kHz sampling rate and 16-bit quantization.[13] The frequencies and amplitudes were analyzed. A large-diaphragm condenser microphone and professional sound recording hardware were used, and all recordings were made in an acoustically treated, silent room. After struck, the TFs were placed 3 cm away from the microphone, and recordings were made.

The frequency with the longest lasting sound energy was accepted as the fundamental frequency of each TF.The next two frequencies with the highest

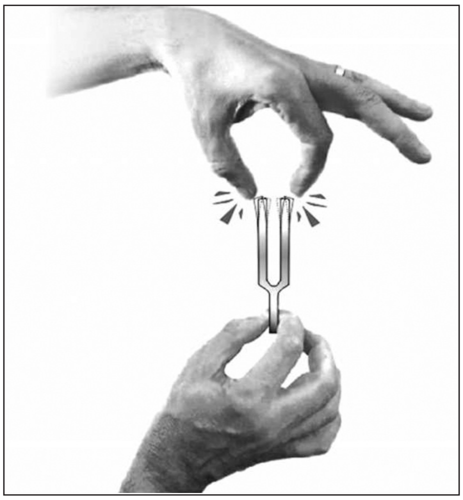

FIGURE 1A: Pinch with Fingers (PwF).

FIGURE 1B: Parallel Position (PA).

amplitude in the recorded sound were taken as the first and second overtones. Decay time was calculated as the period in which the sound amplitude reached to the noise floor of the room, which was 17.25 dB A. Fundamental frequencies and decay times of each TF were obtained from the recordings.

STATISTICAL ANALYSIS

SPSS (SPSS Inc., Chicago, IL, USA) version 20 was used for the statistical analysis of the collected data. Differences between the striking and placement styles were tested with paired samples *t*-tests. For all statistical analysis, the significance level was set as $p < 0.05$.

RESULTS

It was clearly observed that mean decay time by C3-TF was significantly shorter than mean decay time by C2-TF (Table 1) (paired sample *t* test, $p<0.001$). When the first and second conditions (placement style following the PBS strike) were compared (Table 1), fundamental frequencies of the recordings via PA placement were higher than those of PE placement, andthe difference for C2-TF was statistically significant (paired sample *t* test, $p<0.02$). Decay times of the fundamental frequency were also longer in PA placement, with astatistically significant difference found for C3-TF(paired sample*t* test, $p<0.001$).

When the first and third conditions (striking styles) were compared (Table 1), fundamental frequencies produced by both TFs were not statistically different between PBSand PwF (paired sample *t* test, $p>0.05$), and mean decay time of fundamental frequency was significantly longer by PwF than PBSin the recordings taken from C2-TF (paired sample*t* test, $p<0.005$).

FIGURE 1C: Pisiform Bone Strike (PBS).

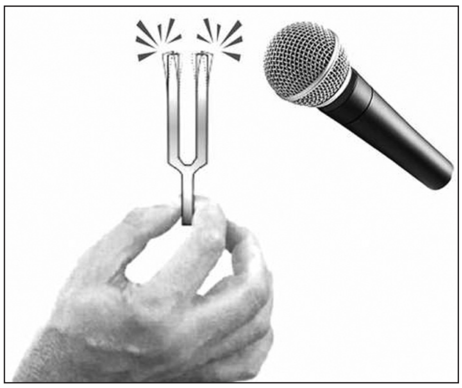

FIGURE 1D: Perpendicular Position (PE).

TABLE 1: Fundamental frequency (FF) first overtone (F1) and second overtone (F2) and their decay times (DTs).

	Frequency (Hz)			Decay Time (seconds)		
	512 Hz (C2) Tuning Forks					
	PwF-PA	PBS-PA	PBS-PE	PwF-PA	PBS-PA	PBS-PE
FF	518,85 ±7,29	518,48 ±7,32	512,57 ±2,69	70,94 ±4,48	67,42 ±5,81	65,45 ±5,43
F1	1121,53 ±69,09	1125,14 ±71,17	1096,92 ±80,61	1,24 ±0,33	1,29 ±0,38	1,42 ±0,46
F2	2303,80 ±185,68	2267,01 ±158,44	2190,26 ±115,04	1,04 ±0,26	1,27 ±0,48	1,84 ±0,91
	1024 Hz (C3) Tuning Forks					
F0	1037,21 ±19,53	1031,37 ±14,74	1025,66 ±9,96	38,69 ±2,91	37,61 ±3,36	30,81 ±4,64
F1	2112,04 ±67,19	2101,12 ±77,73	2044,12 ±27,36	0,24 ±0,54	0,47 ±0,65	0,30 ±0,53
F2	4019,50 ±107,75	3907,19 ±113,69	3854,03 ±132,46	0,03 ±0,08	0,17 ±0,35	0,23 ±0,45

±: indicates standard deviation.

The overtones were found to be smaller in the recordings via PE than PA placement, but the only significant difference was found in the first overtoneby C3-TF. Decay time values were not significantly different between PA and PE placement. ForPwF striking style, second overtone was significantly higher by C3-TF (paired sample *t* test, $p<0.03$), with no meaningful difference in decay times between PBS and PwF striking styles.

DISCUSSION

Nearly 20 different TF tests have been used in the practice of otorhinolaryngology in the last 180 years.[6,14] Although there areno world wide data demonstrating the popularity and use of various striking styles and placements of TFs among physicians, it isestimatedto behighly variable. As an example, Butskiy, Ng, Hodgson and Nunez reported that about 46% of members of the Canadian Society of Otolaryngology-Head &Neck Surgery activated the TF by a strike on the knee, with approximately 32.8% using an elbow strike.[8] According to their survey, a small minority (2.6%) in Canada prefer striking TFs by PwF. Canadian otolaryngologists heldthe TF either parallel or perpendicular to the external ear canal (47% and 45%, respectively). Although we do not have any formal data, as personal observations of the authors for years, PwF is a very common practice in Turkey. To our knowledge, the acoustic properties of PwF have notbeen tested in the literature until our study. In this study, striking by PwF produces a longer pure tone stimulus (almost 3 s in mean) without causing any clinically important change in the fundamental frequencyand overtones, in comparison with the classically recommended PBS (there was only difference in decay time of the second overtones, and it was not longer than 0.31 s).

Previously, Samuel and Eitelberg reported that the muscle-covered bony surface on the elbow did not produce additional overtones as Stevens and Pfannenstiel recently demonstrated by striking the human palm or head.[10,11] Never the less, in the study by Samuel and Eitelberg, additional over tones were produced by striking the C0-TF (128 Hz) and C1-TF (256 Hz) to bony and wooden surfaces, while Stevens and Pfannenstiel found an additional overtone by C1- and C2-TFs by striking to wooden and metal surfaces.[10,11] In our study, the body structures used in both PwF and PBS are muscle covered. In accordance with the previous data, no important overtones aredetected because the duration of both the first and second overtones are very short.[10,11] Mean decay time values of fundamental frequency are between approximately 65 and 71 s by C2-TF, and 31 and 39 s by C3-TF, while mean overtones are not longer than 1.5 s. Hence, it could be said that no additional frequency continues as much as to alter fundamental frequency in our study.

Major stimulation of the cochlea will be achieved at or around the targeted frequencies by the TFs in all conditions tested in this study. However, PE placement of the TFs to the external ear canal decreases the fundamental frequency (particularly by C2-TFs) and decay times (particularly by C3-TFs). That decreasein fundamental frequency (from approximately 519 to 513 Hz by C2-TFs and from approximately 1031 to 1026 Hz by C3-TFs) appearsto be clinically unimportant. This is because the measured fundamental frequencies of PA and PE recordings stimulate the frequency bands around the targeted frequency regions in the cochlea (512 and 1024 Hz, respectively) without causing any interference with other regions. It may be said that PE placement produces an fundamental frequency closer to original frequencies (512 and 1024 Hz).

In our study, the important finding that may affect clinical use of the Rinne test is about decay time of C3-TFs, which is significantly lower by PE placement. PE placement decreases decay time of fundamental frequency in the C3-TF by about 7 s compared with3 s by the C2-TF. This is in accordance with *invitro* findings of experimental data in which PA placement-causes higher sound pressure on the tympanic membrane compared with PE placement Chole and Cook reported that oblique orientation of the TF may-dim inish the intensity of the sound, because the TF generates sound from two sources that interact, forming regions of addition and cancellation of waves.[8,15-17]

In our study, the amplitude of the sound energy (intensity) is not measured, but measuring audible duration of the TF until it lowersto the level of background noise is preferred. Hinchcliffe and Littler noted that the sensitivity of the Rinne test could be improved by measuring the time that elapses between cessation of bone and air conduction.[18] That is, the "time method" for the Rinne test.[17-19] Butskiy, Ng, Hodgson and Nunez found that the mean of the sound intensity recorded at the tympanic membrane with C2-TFs in PA rather than PE placement was louder by 2.5 dB for the fundamental frequency.[8] Hence, the 7-s difference in decay times of fundamental frequencies that was found in our study could be a major disadvantage for PE placement of C3-TFs, particularly in a noisy outpatient clinic.

There islimited published research about TFs. Butskiy, Ng, Hodgson and Nunez reported data for C1- and C2-TFs.[8] When their data are compared with the findings in our study, the mean frequency of the second overtone issmaller in our study (between approximately 2190 and 2304 Hz). Butskiy, Ng, Hodgson and Nunez recorded the first and second overtones in 1 and 3.15 kHz by knee strike via both PA and PE placement.[8] Although means of the first overtones (1125 and 1121 Hz by PBS and PwF tinning via PA placement, respectively) in our study arein accordance with Butskiy, Ng, Hodgson and Nunez data, the second overtones are not (2267 and 2302 Hz by PBS and PwF strike via PA placement, respectively).[8] Further, PBS tinning via PE placement did not present any significant difference in the mean of the first and second overtones (about 1097 and 2190 Hz, respectively; Table 1). The differences in the second overtone frequency may be related to the material composition of the TFs used in the studies or description of the overtones. Butskiy, Ng, Hodgson and Nunez described overtones according to amplitude, while duration is used in the current study; therefore, the second longest one is the first overtone, and the third longestis the second overtone. Conversely, it maysimply be due tousing aknee strike.

CONCLUSION

It is concluded that striking styles and placement angles present neither significant difference in fundamental frequency nor additional frequencies, which could alter fundamental frequency. However, lower decay time measured in PE placement,particularly by C3-TFs, may be important for aclinical decision based on the Rinne test when the "time method" is used to determine the air-bone gap with the threshold comparison method. Rinne test may be negative, even if the air-bone gap in an audiogram is not much larger. Further, our data point out that PwF may be an alternative tinning method providing longer decay time without changes in the targeted frequency.

Source of Finance

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Süleyman Boynueğri, Yusuf Kemal Kemaloğlu;* ***Design:*** *Süleyman Boynueğri, Yusuf Kemal Kemaloğlu;* ***Control/Supervision:*** *Yusuf Kemal Kemaloğlu;* ***Data Collection and/or Processing:*** *Mustafa Yüksel, Süleyman Boynueğri;* ***Analysis and/or Interpretation:*** *Mustafa Yüksel;* ***Literature Review:*** *Mustafa Yüksel;* ***Writing the Article:*** *Mustafa Yüksel, Yusuf Kemal Kemaloğlu;* ***Critical Review:*** *Yusuf Kemal Kemaloğlu;* ***References and Fundings:*** *Yusuf Kemal Kemaloğlu.*

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