Transmission of sound by bone conduction

There is another route by which sound can reach the inner ear: by conduction through the bones of the skull. When the handle of a vibrating tuning fork is placed on a bony prominence such as the forehead or mastoid process behind the ear, its note is clearly audible. Similarly, the ticking of a watch held between the teeth can be distinctly heard. When the external canals are closed with the fingers, the sound becomes louder, indicating that it is not entering the ear by the usual channel. Instead, it is producing vibrations of the skull that are passed on to the inner ear, either directly or indirectly, through the bone.

The higher audible frequencies cause the skull to vibrate in segments, and these vibrations are transmitted to the cochlear fluids by direct compression of the otic capsule, the bony case enclosing the inner ear. Because the round window membrane is more freely mobile than the stapes footplate, the vibrations set up in the perilymph of the scala vestibuli are not canceled out by those in the scala tympani, and the resultant movements of the basilar membrane can stimulate the organ of Corti. This type of transmission is known as compression bone conduction.

At lower frequencies—i.e., 1,500 hertz and below—the skull moves as a rigid body. The ossicles are less affected and move less freely than the cochlea and the margins of the oval window because of their inertia, their suspension in the middle-ear cavity, and their loose coupling to the skull. The result is that the oval window moves with respect to the footplate of the stapes, which gives the same effect as if the stapes itself were vibrating. This form of transmission is known as inertial bone conduction. In otosclerosis the fixed stapes interferes with inertial, but not with compressional, bone conduction.

In persons with middle-ear disease, hearing aids with special vibrators are sometimes used to deliver sound to the mastoid process (the part of the temporal bone behind the ear); the sound is then conducted by bone to the inner ear. Bone conduction is also the basis of some of the oldest, simplest, and most useful tests in the repertoire of the otologist. These tests employ tuning forks to distinguish between conductive impairment, which affects the middle ear and is amenable to surgery, and sensorineural impairment, which affects the inner ear and the cochlear nerve and for which surgery usually is not indicated.

Effect of interpretive bias on research evidence

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BMJ. 2003 Jun 28; 326(7404): 1453–1455.

Can Bone Conduction Thresholds Really Be Poorer Than Air?

S. Joseph Barry
https://doi.org/10.1044/1059-0889.0303.21

"Can Bone Conduction Thresholds Really Be Poorer Than Air?." *American Journal of Audiology*, 3(3), pp. 21–22

Automated Smartphone Audiometry: A Preliminary Validation of a Bone-Conduction Threshold Test App

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Nicholas A. Dewyer, MD, Patpong Jiradejvong, MS, David S. Lee, BA, ...Published February 11,

2019 Research Article
https://doi.org/10.1177/0003489419828770

J Am Acad Audiol. 2015 Jan;26(1):101-8. doi: 10.3766/jaaa.26.1.11.

Air conduction, bone conduction, and soft tissue conduction audiograms in normal hearing and simulated hearing losses.

Adelman C[1], Cohen A[2], Regev-Cohen A[2], Chordekar S[3], Fraenkel R[2], Sohmer H[4]

J Am Acad Audiol. 2015 Jul-Aug;26(7):645-51. doi: 10.3766/jaaa.14105.

Bone Conduction Thresholds without Bone Vibrator Application Force.

Geal-Dor M[1,2], Chordekar S[1,3], Adelman C[1,2], Sohmer H[4].

Hear Res. 2018 Jul;364:59-67. doi: 10.1016/j.heares.2018.03.030. Epub 2018 Apr 3.

Does hearing in response to soft-tissue stimulation involve skull vibrations? A within-subject comparison between skull vibration magnitudes and hearing thresholds.

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Abstract:
Hearing can be elicited in response to bone as well as soft-tissue stimulation. However, the underlying mechanism of soft-tissue stimulation is under debate. It has been hypothesized that if skull vibrations were the underlying mechanism of hearing in response to soft-tissue stimulation, then skull vibrations would be associated with hearing thresholds. However, if skull vibrations were not associated with hearing thresholds, an alternative mechanism is involved. In the present study, both skull vibrations and hearing thresholds were assessed in the same participants in response to bone (mastoid) and soft-tissue (neck) stimulation. The experimental group included five hearing-impaired adults in whom a bone-anchored hearing aid was implanted due to conductive or mixed hearing loss. Because the implant is exposed above the skin and has become an integral part of the temporal bone, vibration of the implant represented skull vibrations. To ensure that middle-ear pathologies of the experimental group did not affect overall results, hearing thresholds were also obtained in 10 participants with normal hearing in response to stimulation at the same sites. We found that the magnitude of the bone vibrations initiated by the stimulation at the two sites (neck and mastoid) detected by the laser Doppler vibrometer on the bone-anchored implant were linearly related to stimulus intensity. It was therefore possible to extrapolate the vibration magnitudes at low-intensity stimulation, where poor signal-to-noise ratio limited actual recordings. It was found that the vibration magnitude differences (between soft-tissue and bone stimulation) were not different than the hearing threshold differences at the tested frequencies. Results of the present study suggest that bone vibration magnitude differences can adequately explain hearing threshold differences and are likely to be responsible for the hearing sensation. Thus, the present results support the idea that bone and soft-tissue conduction could share the same underlying mechanism, namely the induction of bone vibrations. Studies with the present methodology should be continued in future work in order to obtain further insight into the underlying mechanism of activation of the hearing system.

Dirks, D., and Malmquist, C.(1969). “Comparison of frontal and mastoid bone-conduction threshold in various conductive lesions,” J. Speech Hear. Res. **12**, 725–746. Google ScholarCrossref

Unoccluded and occluded bone conduction (BC) and Sensorineural Acuity Level (SAL) thresholds at the frontal bone and the mastoid process were compared on 60 subjects with conductive hearing loss. The results were based on calibrated norms obtained on 32 subjects with normal hearing and validated on 10 cases with sensorineural hearing loss. The mastoid BC thresholds for the entire conductive group were more depressed than comparable frontal measurements, but the average difference was only five dB. The threshold data for subjects with surgically confirmed middle-ear lesions (N = 38) were analysed in greater detail by dividing the group by frontal-mastoid differences and observed physical changes within the middle ear. Approximately 20% of the group showed frontal-mastoid differences that exceeded the normal range, and these cases had either malleus fixation or an ossicular discontinuity due to incus necrosis or absence of the incus. Average results for 17 cases with stapes fixation suggested that there were no frontal-mastoid differences and that both BC curves were somewhat similarly influenced by the middle-ear impairment. The SAL and occluded BC thresholds at the frontal bone were always in close agreement and differed from the unoccluded frontal-bone measurements for the conductive cases by the amount of the average occlusion effect observed for normals. The advantages of unoccluded bone conduction at the frontal bone are stressed, and the possible use of a comparison of BC thresholds at the two sites for diagnostic purposes is suggested.

Dirks, D., and Swindeman, J. (**1971**). "The variability of occluded and unoccluded bone-conduction thresholds," in *Hearing Measurement: A Book of Readings*, edited by I. Ventry, J. Chaiklin, and R. Dixon (Appleton-Century-Crofts, New York), pp. 158–169. **Google Scholar** JSHLR 1967

A series of three experiments of similar basic design was performed on individuals with normal hearing to compare the variability associated with occluded and unoccluded bone-conduction thresholds.

Estimates of threshold were obtained at each test frequency for air conduction, unoccluded bone conduction, and occluded bone conduction stimuli. Eleven young adults participated in Experiment I. Their ears were occluded by TDH-39 earphones encased in MX41/AR cushions. In Experiment II 11 young adults were tested with a Grason-Stadler 001 circumaural cushion replacing the MX41/AR cushion. Two types of occluders were compared in Experiment III, using nine subjects with previous experience in Bekesy tracing.

The variability of the occluded bone-conduction thresholds was either similar or less than that observed during the unoccluded measurements. The variability of the occlusion effect itself was comparable or less than the variability of the unoccluded or occluded bone-conduction thresholds. The source of the variability stemmed largely from differences between individuals rather than from test-retest variability. Although the variability of the occluded thresholds was reduced slightly when the circumaural cushion was used as

compared to the supra-aural cushion, the results of the final experiment did not completely support the earlier finding.

Changes in Bone-Conduction Thresholds Produced by Masking in the Non-Test Ear

Donald Dirks
and
Carolyn Malmquist JSHLR Sept 1 1964

Hearing Level Versus Sound Pressure Level: A Brief Survey

-
- George R. Simon and
- Jerry L. Northern

https://doi.org/10.1044/jshr.1001.156

Figure 3. Average Air and Bone Conduction Thresholds for 20 ears of 10 normal-hearing subjects.

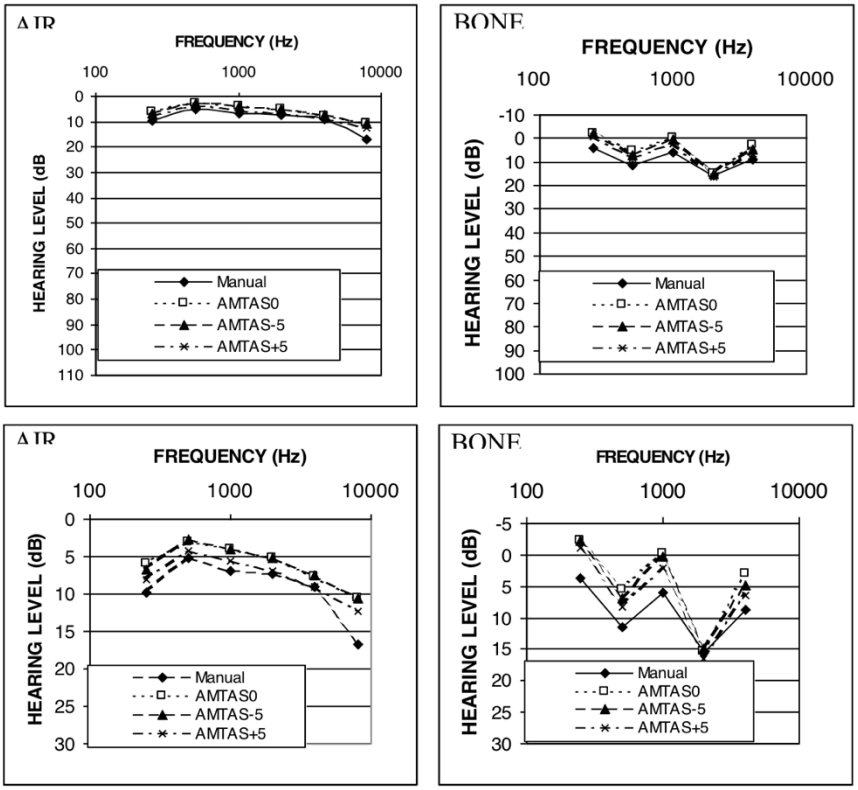


Figure 4. Distribution of Air Conduction Threshold Differences for Normal Subjects

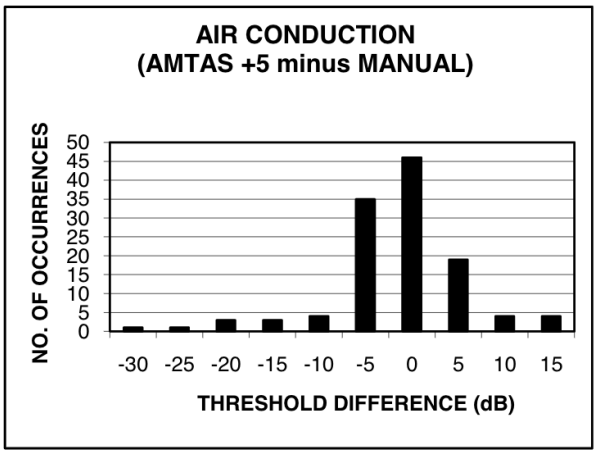
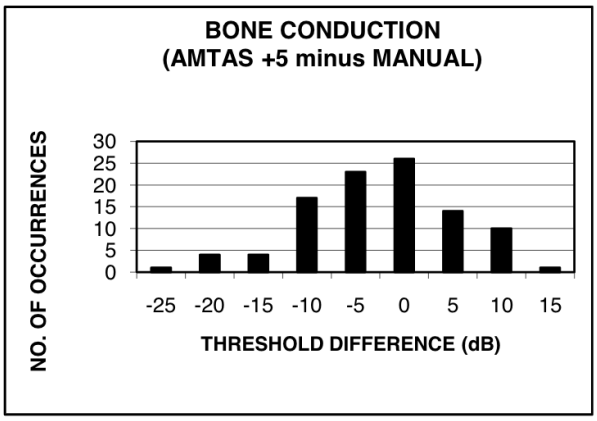


Figure 5. Distribution of Bone Conduction Threshold Differences for Normal Subjects



4. Bone Conduction

Although bone conduction testing is usually performed with the bone vibrator on the mastoid, there are many advantages to placing the vibrator on the forehead. These include a) eliminating the need to move the transducer during the test, b) lower intersubject variability, c) more stable placement, and d) less influence by middle ear conditions. Forehead testing requires more output from the audiometer which has been a limitation but modern instruments are capable of providing adequate stimulation levels for forehead testing. The elimination of the need to move the transducer to test the other ear is an efficiency that makes it possible to obtain a complete air- and bone-conduction audiogram with masking without moving the transducers.

dB differences. The proportion of threshold differences exceeding 10 dB was 10%, identical to the corresponding proportion for air conduction. The differences in the distribution of differences for air conduction and bone conduction probably results from the greater variability of bone conduction threshold testing that is largely due to variability in coupling of the bone vibrator to the skull and transmission of vibratory stimuli to the inner ear.

4. Bone Conduction Headband Force Levels

The ANSI audiometer standard (ANSI S3.21-2004) specifies that the bone vibrator should be placed on the head with a coupling force of 5.4 N $\pm$ 0.5 N (551 g $\pm$ 51 g). An elastic headband was designed for forehead bone conduction that provides the specified force for average head sizes.

Table 4 shows force measurements for three headbands of the preferred size for ten adult subjects. Table 5 shows the 10-90 %ile range for males and females for 3 age groups. The average head size of our subjects (22.6 in) is within the 10-90 %ile ranges for male and female 18-year olds.

Table 4. Bone Conduction Headband Force Measurements

				Headband			
Subject	Age	Sex	Circum (in)	1	2	3	Avg
JM	57	F	23.00	506	470	590	522
BNM	16	F	20.25	520	452	528	500
JCM	18	F	23.00	620	602	616	613
JB	30	M	24.00	650	720	680	683
AK	39	F	22.00	470	540	470	493
KW	18	F	21.25	520	480	506	502
NW	18	F	23.00	648	614	636	633
MZ	70	M	23.00	658	520	630	603
LB	60	M	24.50	700	658	684	681
CK	45	F	22.00	456	444	460	453
Mean	37		22.60	575	550	580	568
S.D.	20		1.26	89	95	83	84

Force was measured by placing the bone vibrator (B71) on the forehead held in place by the headband. The force required to just separate the headband from the head was measured. The mean force was 568 g (s.d. = 84 g). This value is within 3% of the force level specified in the standard.

Table 5. Normative head circumference (from Roche et al., 1987, Pediatrics, 79, 706-712)

		Roche et al. 10th - 90th %ile			
		female		male	
		cm	in	cm	in
5 yr olds	10th	49.02	19.30	49.83	19.62
	90th	52.37	20.62	53.30	20.98
12 yr olds	10th	51.35	20.22	52.35	20.61
	90th	55.12	21.70	56.20	22.13
18 yr olds	10th	53.33	21.00	54.50	21.46
	90th	57.47	22.63	58.68	23.10

From Audiometry Margolis

In 1978 The American National Standards Institute (ANSI) published the American National Standard Methods for Manual Pure-Tone Threshold Audiometry (ANSI S3.21-1978). The standard specified many variables inherent in threshold testing, utilizing the familiar “10-down 5-up” method of Hughson and Westlake. It provides an excellent guideline for manual audiometry. But many variables were not specified. The number of ascending and descending stimulus sequences is not specified, nor is there a governing rule or guideline. There is no rule for testing interoctave frequencies. Masking in airconduction testing is described in two sentences, with no operational rules governing masker levels or validation of masked thresholds. Even with the lack of specificity of the standard, some of the recommended methodological variables are routinely ignored by clinical audiologists. Early in the training and experience of audiologists, clinicians begin to take shortcuts which are not governed by formal rules or principles. Many audiologists become highly skilled at obtaining accurate audiograms despite the lack of standardization However, the lack of standardization results in a level of uncertainty of which, I believe, we are all at least somewhat aware. It is not uncommon for audiograms to be repeated in one clinic based on a lack of confidence in results recently obtained in another clinic. When hearing testing is needed for research purposes, such as studies of effects of treatments on hearing, it is difficult to justify test methods so devoid of standardization.

Skilled audiologists make observations of patient behavior which impacts diagnosis and treatment including false positive responses, delays in response latency, inconsistency throughout the evaluation, and testretest reliability, all of which contribute to the audiologist’s judgment of the accuracy of the audiogram and the need for further testing -- but these factors are not formally incorporated in audiometric methods.

Margolis RH, Saly GL: Distribution of hearing loss characteristics in a clinical population. Ear Hear 2008a;29:524-532

Frank T, Holmes A: Acoustic radiation from bone vibrators. Ear Hear 1981;2:59-63.

Hall Hearing Journal 20 questions

2 But now that we all do immittance and OAEs routinely, is boneconduction testing still necessary?

In this era of managed care and healthcare cost containment, when every clinical minute counts, we shouldn't perform any audiologic procedure that adds nothing to the diagnosis and does not contribute to patient outcome. If aural immittance findings (tympanometry and acoustic reflexes) are entirely normal and, especially, if OAEs are well within normal limits, then bone-conduction pure-tone audiometry has no clinical value. It's a waste of precious clinical time and an unnecessary clinical expense. However, for patients who lack these criteria for normal middle ear function, bone-conduction audiometry is definitely in order.

8 That is an oldie! So old, in fact, that I've never used it. What advantage does the SAL procedure have over conventional bone-conduction audiometry?

The sensorineural acuity level (SAL) procedure offers several advantages over conventional bone-conduction measurements. With this technique, masking noise is delivered to both ears via bone conduction, with the bone oscillator located on the forehead. The essence of the masking dilemma—crossover of the masking noise to the test ear—is immediately eliminated. There's also a very practical advantage for the busy audiologist. The SAL procedure is performed with earphones on both ears or, better yet, with insert earphone cushions within each ear canal. This eliminates the repeated need to run into the sound booth to reposition the bone oscillator on the mastoid of the test ear and the earphone for masking on the non-test ear.

13 Well, it sounds as if the old SAL test still has some life left in her. Are there any other tricks in your bag for dealing with the clinical challenges (limitations) of BC audiometry?

Yes, three to be precise. One is the audiometric Weber test, a very simple technique that anyone can perform before or after boneconduction pure-tone measurements. Although it's been around for years, the audiometric Weber remains on the fringe of clinical practice. It's really just the old Weber test performed with an audiometer instead of tuning forks.

The bone oscillator is placed on the forehead and the patient is instructed to lateralize the sound, i.e., point to the ear where the sound is heard. Then, pure tones (250, 500, and 1000 Hz) are delivered via bone conduction at a modest intensity level (about 20 dB above unmasked or bone-conduction thresholds for the apparently better cochlea). For each test frequency, the patient will lateralize the signal to the better hearing ear for sensory hearing loss, and the poorer hearing ear for conductive hearing loss. In a matter of minutes, the audiologist can begin the process of differentiating among conductive, sensory, and mixed

Stenfelt, S., Hato, N. & Goode, R.L. 2002. Factors contributing to bone conduction: the middle ear. J Acoust Soc Am, 111, 947/959.
Stenfelt, S., Wild, Y., Hato, N. & Goode, R.L. 2003. Factors contributing to bone conduction: The outer ear. J Acoust Soc Am, 113, 902/913.
hearing losses for each ear.

International Journal of Audiology 2005; 44:302/306 Influence of ear canal occlusion and static pressure difference on bone conduction thresholds: Implications for mechanisms of bone conduction

Huizing (1960) made thorough studies of the influence of the middle ear on BC thresholds for frequencies up to 8.0 kHz; he used mass loading of the eardrum, air pressure changes, and occlusion of the ear canal. Similar measurements were performed by Kirikae (1959), Legouix and Tarab (1959), Tonndorf (1966), and Khanna et al. (1976). The results of all of these studies suggest that the status of the middle ear can have an important influence on BC thresholds. Occlusion of the ear canal also has an important influence.

Thus, for normally hearing people, when the ear canal is occluded, most low-frequency BC sound reaching the cochlea is transmitted through the external ear canal and then through the middle ear (Zwislocki, 1975; Stenfelt et al, 2003). It would be expected, therefore, that BC thresholds would be affected by the middle ear status after occlusion of the ear canal

EFFECT OF BONE CONDUCTION TRANSDUCER PLACEMENT ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS DISSERTATION Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University By Julie L. Hazelbaker, M.A. ***** The Ohio State University 2004

However, are there differences in the cochlear responses when the skull is stimulated at different locations? The contributions of the outer and middle ears are reported to vary at the three locations (Dirks, 1978). Can the inner ear component at the different placements be isolated?

Bekesy (1932, 1960) also asserted that the primary vibratory energy pathway from the skull to the inner ear was through bone (completely osseous). Other studies (i.e. Wever & Lawrence, 1954) emphasized the osseous pathway taken by bone conducted sounds and the minimal contribution of the non-osseous pathways via tissue and other skull contents.

Tonndorf reported three major osseous routes of bone conducted sound (see Figure 2). The outer ear component, often called the 9 osseo-tympanic component, is created as skull vibrations radiate into an occluded external meatus producing sound waves which act on the tympanic membrane, just as in air conduction. This “occlusion effect” is greater for lower frequency stimuli and is negligible for frequencies 2000 Hz or greater. The middle ear component, called the inertial component, occurs due to the relative motion between the vibrations of the cochlear shell and the ossicular chain. This motion leads to the same type of cochlear fluid displacement produced by air conducted sounds. The compressional/distortional inner ear component is

created by vibration of the temporal bone which in turn creates deformation in the cochlear bony shell and fluid displacements in and out of the cochlear windows. The round window augments the response and the oval window reduces the amount of energy acting on the cochlear partition. The sum total of all communications of the intracochlear spaces acts as a “third window” (Tonndorf, 1968). This energy in the form of a traveling wave, creates basilar membrane displacement and excitation of the outer hair cells.
The stimulus that eventually reaches the cochlea with BC stimulation is a combination of energy from several pathways.

Despite these advantages of forehead placement, the main disadvantage is that the dynamic range is smaller since thresholds are typically greater. Therefore, mastoid placement is favored clinically due to the greater dynamic range. Additionally, it is often reported that there is no interaural attenuation to consider in bone conduction testing (Martin, 1997), that the signal reaches both cochleae at equal magnitudes. This is not completely true for mastoid oscillator placement. Interaural attenuation values can be as much as 15 dB at 2000 Hz and 20 dB at 4000 Hz, which is a second advantage for ipsilateral mastoid placement (Silman & Silverman, 1991).

Dirks, D. 1964. Bone conduction measurements. Arch Otolarygol. 79, 594-599. Dirks, D. 1964. Factors related to bone conduction reliability. Arch Otolarygol. 79, 551- 558. Dirks, D., Malmquist, C. 1969. Comparison of frontal and mastoid bone-conduction thresholds in various conductive lesions. J. Speech Hearing Res., 12, 725-746.

Distribution Characteristics of Normal Pure-Tone Thresholds Robert H. Margolis1, Richard H. Wilson2, Gerald R. Popelka3, Robert H. Eikelboom4,5,6, De Wet Swanepoel4,5,6, and George L. Salyt

Conclusions

The positive shift and skew of the manual audiometry data may result from tester bias. The striking scarcity of thresholds below 0 dB HL suggests that audiologists place less importance on identifying low thresholds than they do for higher-level thresholds. We refer to this as the *Good Enough Bias* and suggest that it may be responsible for differences in distributions of thresholds obtained by automated and manual audiometry.

https://hearinghealthmatters.org/waynesworld/2013/trivia-history-hearing-testing/

Hhistory of audiology trivia questions on audiometers Wayne Staab