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# Rinne Test Results: How Badly Can We Be Mistaken?

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## Abstract

*Objective.* To establish the extent to which sound amplitudes delivered by a vibrating tuning fork change around its long axis and to evaluate whether such differences in amplitude might change the results of the Rinne test.

*Study Design.* Experimental measurements.

*Setting.* Laboratory setting.

*Methods.* Setup I: a vibrating tuning fork was handheld and manually rotated around its long axis next to a sound recording device (the simulated ear) in order to record sound amplitude data at a full range of angles relative to the device; files were split into segments in which sound amplitude changed: A (from a maximum to a minimum) and B (from a minimum to a maximum). Setup II: a vibrating tuning fork was machine-rotated, and the angle of rotation, along with the sound amplitude, was automatically recorded through a single full rotation.

*Results.* The angles of 0° and 180° (which equate to the established best practice in Rinne testing) were associated with the highest sound amplitudes. All other angles decreased sound amplitude. The greatest decrease in amplitude was recorded at 51° and 130°. This difference ranged from 9.8 to 34.7 dB, depending on the initial amplitude.

*Conclusion.* The outcome of a Rinne test can be affected if attention is not paid to the precise angle at which the tuning fork is held relative to the ear. The potential of this effect will be greater when high background noise or patient hearing loss requires that the tuning fork be vigorously excited to obtain high sound amplitudes.

## Keywords

tuning fork, Rinne test, air conduction, bone conduction, hearing loss

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Of the wide spectrum of existing clinical tuning fork tests, the Rinne test is a very simple and reliable way to verify conductive hearing impairment.[1,2] There are variations in how the Rinne test is performed,[3] and it is thus considered highly individually dependent, mostly due to differences in how the tuning fork (TF) is placed relative to the ear when evaluating air conductions.

The Rinne test is based on the acoustic impressions of the examinee and compares the lowest audible sound amplitudes for air and bone conduction. Therefore, subtle differences in sound amplitude resulting from variations in TF position by the ear during air conduction testing may change the test result, given that perception via bone conduction does not vary depending on TF position.

The physical nature of a vibrating tuning fork has been investigated in numerous physical studies explaining the nature of the sound spectrum, sound wave propagation, and sound wave interferences. It has been proved that the sound from a vibrating tuning fork decays over time and the sound amplitudes are unevenly distributed around the TF. Each vibrating tine creates 2 longitudinal waves in the surrounding air, which propagate and interfere with each other. Close to the TF, destructive interference occurs, that is, acoustic waves are cancelled out (the cancellation effect). This is perceived by the examinee as a significant reduction in sound amplitude (ie, muting). During a whole single rotation of the TF around its long axis, the sound perceived from a fixed point gets quieter and then louder 4 times (2 cycles per half turn of the symmetrical device).[4] The angles at which the cancellation effect occurs vary depending on the size of the TF and the distance between TF and receiver (microphone or ear). Nevertheless, all locations of the cancellation are within the hyperbolic borders extending from the TF,[5] somewhere around the 45° and 135° angles of each half turn.[6,7]

As mentioned above, Rinne test results are highly dependent on the conditions of individual iterations of the test. Variability derives from where and how the TF is placed next to the ear when evaluating air conductions. Incorrectly

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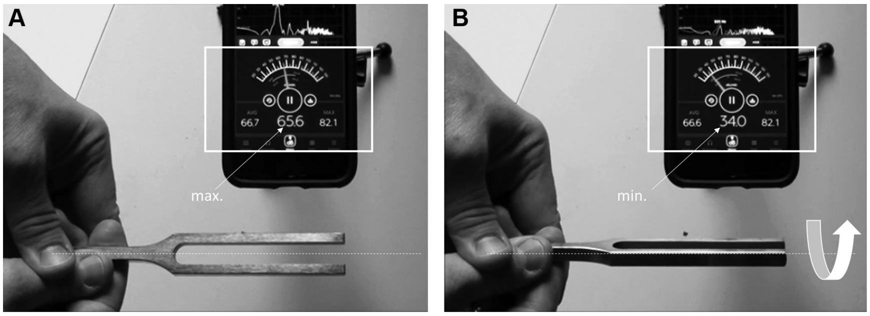

**Figure 1.** Clinical setup of experiment with handheld tuning fork with long axis parallel to baseline of the measuring instrument.

positioning the tuning fork within cancellation angles by the ear during the Rinne test will change the perception of sound amplitude and can thus potentially alter test results.

Thus, the research objective was to measure the extent to which the perception of sound amplitude is affected by variations in TF angle relative to the ear during the air conduction part of the Rinne test. More specifically, the objective was to establish the range of differences in amplitude between a TF positioned at the ''best'' and ''worst'' angles.

## Methods

Measurements were conducted in two setups: (I) a clinical setup mimicking a Rinne test performed under clinical conditions, and (II) a laboratory setup to obtain information on precise tuning fork angles and their related sound amplitudes. Both setups used the same metal alloy; a 512-Hz, 2-tine tuning fork excited by a rubber hammer; and electronic devices to record, store, and measure sound amplitudes and angles of the vibrating tuning fork.

### *Clinical Setup*

Mimicking the human ear, an iPhone 8 (software 12.4.1; Apple) running the application DeclibelX:dB Sound Level Meter Version 8.1.3 by Sky Paw Co. Ltd was used to measure sound amplitudes at various angles of the vibrating tuning fork placed by the device microphone. The accuracy and sensitivity of the device microphone were checked for both frequency and amplitude detection in an audiobooth: the results of the sound frequency and amplitude detected by the audiobooth headphones were compared against those registered on the device (frequencies: 500, 1000, 2000 Hz; amplitudes: 40, 50, 60, 70 dB). The background noise level of the examination room was measured as ranging from 33.20 to 33.90 dB.

The excited TF was held with its long axis parallel to the line of the device's ''bottom end'' (where its speakers and microphone are located) at a distance of 4 cm (**Figure 1**). Measurements—sound amplitude values of the vibrating TF—were displayed on the measuring device. The device screen was video recorded for subsequent manual extraction of the measurement data for analysis.

The recording was made as the vibrating TF was rotated by hand until the recorded sound amplitude reached background noise level. This process was repeated for 20 iterations. In preprocessing, the recording was split by performing a cut at each point where the sound amplitude reached a maximum and at each point where it reached a minimum, resulting in a total of 229 sample segments. The sample segments were categorized into 2 groups, as follows: (A) samples for which the recorded sound amplitude went from a maximum to a minimum as the TF was rotated and (B) samples for which the amplitude went from a minimum to a maximum.

Statistica software (v.13; StatSoft) was used to perform the statistical analysis. Descriptive statistics such as mean median, minimum, maximum, lower and upper quartiles, and standard deviation were used to describe continuous variables. Student *t* test was used to compare calculation of the A and B groups. For the purposes of determining how TF angle–related muting differs between various amplitude ranges, the Kruskal-Wallis test was used to analyze differences between subgroups (designated at 10-dB intervals) within groups A and B. In all cases, the level of statistical significance was set at $P < .05$.

### *Laboratory Setup*

Tests and measurements were conducted in a laboratory equipped with a COACH system (Centre for Microcomputer Application) and Coach 6 software. Sound amplitude was registered by a microphone positioned 4 cm from the TF tine. The tuning fork was attached (tines pointing upward) to a rotating base. The starting point position (0°) of the TF was designated such that, looking from the perspective of the microphone, you would only see 1 tine (the other being hidden behind it) (**Figure 2**). The vibrating TF was rotated at a constant rate of 26° per second; the audio sampling rate was 100 measurements per second. The obtained data—sound amplitudes and tuning fork angles—were recorded automatically, stored, and analyzed.

The current project is not a medical experiment and thus does not require a separate approval, as confirmed by the Bioethics Committee of the Nicolaus Copernicus University in Torun.

## Results

### *Clinical Setup*

In group A (maximum to minimum; n = 136), initial amplitudes (maxima) were in the range from 81.50 to 48.00 dB; meanwhile, their minima were in the range from 60.90 to 33.50 dB. Within individual sample segments, the change in

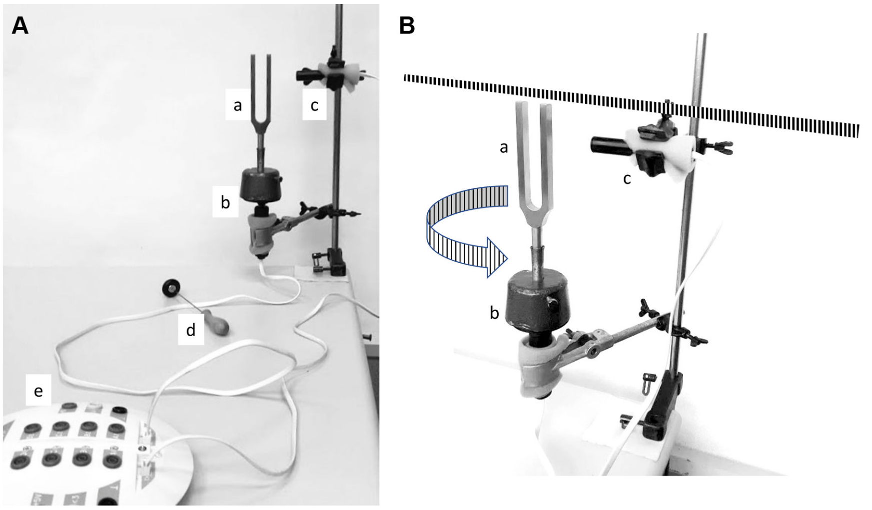

**Figure 2.** Laboratory setup: tuning fork (a) mounted on swivel base (b) and microphone (c) located 4 cm from tuning fork tine, connected to the measuring device (e). (d) Rubber hammer.

**Table 1.** Descriptive Statistics for Group A (Change in Amplitude From Maximum to Minimum) and Group B (Change in Amplitude From Minimum to Maximum).

| Variable | n | Mean, dB | Median, dB | Minimum, dB | Maximum, dB | Lower Quartile | Upper Quartile | Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| Group A | | | | | | | | |
| High value | 136 | 65.40 | 64.30 | 48.00 | 81.50 | 59.00 | 72.30 | 8.69 |
| Low value | 136 | 42.61 | 41.40 | 33.50 | 60.90 | 37.30 | 47.85 | 6.57 |
| Delta A[a] | 136 | 22.80 | 23,25 | 13.20 | 34.70 | 19.50 | 25.70 | 4.38 |
| % drop | 136 | 34.84 | 34.83 | 23.08 | 47.24 | 31.75 | 37.69 | 4.86 |
| Group B | | | | | | | | |
| Low value | 93 | 40.59 | 39.60 | 33.20 | 55.20 | 35.70 | 44.20 | 5.79 |
| High value | 93 | 58.38 | 57.10 | 44.00 | 73.10 | 52.20 | 64.20 | 7.37 |
| Delta B[a] | 93 | 17.79 | 17.90 | 9.80 | 23.50 | 15.90 | 19.80 | 3.03 |
| % increase | 93 | 44.27 | 44.73 | 27.93 | 62.10 | 38.88 | 50.42 | 7.81 |

[a] Delta is an absolute value denoting change, rather than increase or decrease; as such, it has no sign.

amplitude (delta) from maximum to minimum ranged from 34.70 to 13.20 dB, with an average of 22.80 dB. This equates to a 34.84% decrease relative to initial amplitude (**Table 1**).

The largest mean decrease (delta = 26.00 dB) among group A samples was observed in the samples with the loudest preliminary acoustic sounds, whereas the smallest decrease (delta = 14.42 dB) was found in the samples with the lowest preliminary amplitudes (**Table 2**). The Kruskal-Wallis $H$ test (4, N = 136) = 57.62 ($P$ = .0001) indicated significant differences between subgroups within delta A results.

In group B (minimum to maximum; n = 93), initial amplitudes (minima) were in the range from 33.50 to 60.90 dB, while the maxima were in the range from 48.00 to 81.50 dB. The increase in amplitude (delta) from minimum to maximum ranged from 9.80 to 23.50 dB, with an average of 17.79 dB. This equates to a 44.27% increase over the initial amplitude (**Table 1**).

The increase in amplitude among the group B (minimum to maximum) samples is greatest for those at midrange amplitudes (40-49 dB) (delta = 19.17 dB). The highest percentage increase (46.29%) was observed in recordings for which initial amplitudes were lowest (in the 30- to 39-dB range) (**Table 2**). The Kruskal-Wallis $H$ test (2, N = 93) = 13.14 ($P$ = .0014) indicated significant differences between subgroups within delta B results.

Student $t$ test was used to compare mean values of delta A and delta B. The results indicate a significant difference at $P < .0000$ ($t(227) = 9.56$; $P = .0000$) (**Figure 3**).

### Laboratory Setup

The maximum amplitudes recorded during the experiment were 80, 70, and 72 dB for tuning fork angles of 0°, 90°, and 180°, respectively. The minimum amplitude values were recorded at 51° and 130°, allowing these to be defined as ‘‘cancellation angles.’’ At each of the cancellation angles, the amplitude was at the lower limit of the microphone's sensitivity—46 dB. The rate of sound decay, as averaged from initial amplitude (at 0°) and final amplitude (360°; ie, the return to 0°), was 0.69 dB per second.

**Table 2.** Descriptive Statistics—Differences in Delta Between Subgroups Distinguished by Preliminary Sound Intensity.

| Group (dB range) | N | Mean | Medial | Maximum | Minimum | Lower quartile | Upper quartile | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Group A | | | | | | Delta A | | |
| 80-89 | 3 | 26.00 | 27.30 | 19.60 | 31.10 | 19.60 | 31.10 | 5.86 |
| 70-79 | 43 | 25.64 | 25.40 | 17.20 | 34.70 | 23.30 | 28.10 | 3.53 |
| 60-69 | 51 | 23.42 | 23.40 | 15.20 | 30.00 | 21.90 | 25.40 | 3.23 |
| 50-59 | 34 | 19.21 | 19.15 | 13.20 | 25.40 | 17.10 | 21.00 | 2.98 |
| <40-49 | 5 | 14.42 | 14.60 | 13.20 | 15.10 | 14.40 | 14.80 | 0.73 |
| Group B | | | | | | Delta B | | |
| 50-59 | 7 | 17.96 | 17.90 | 14.60 | 21.20 | 16.10 | 19.40 | 2.18 |
| 40-49 | 37 | 19.17 | 19.20 | 13.10 | 23.50 | 17.40 | 21.00 | 2.55 |
| 30-39 | 49 | 16.72 | 16.50 | 9.80 | 22.90 | 14.70 | 18.60 | 3.08 |

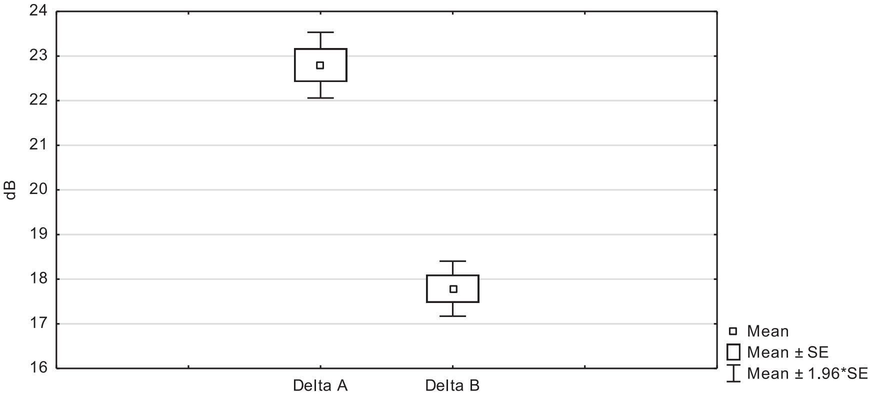

**Figure 3.** There was a significant statistical difference between calculated delta for groups A and B: Student *t* test, $t(227) = 9.56$ ($P = .0001$).

## Discussion

The sensitivity of the 512-Hz Rinne test has been found to vary greatly depending on the experience of the tester, but it can still be very accurate, correctly distinguishing, at up to 96%, between sensorineural and conductive losses.[2,8]

The laboratory setup of the experiment precisely defined the angles at which the cancellation effect occurred. Cancellation was observed at 51° and 130° of each half turn of the tuning fork (**Figure 4**). These values are consistent with previous experiments,[6] indicating that the angles at which the cancellation effect occurs are within the hyperbolic borders extending from the TF[5] somewhere around 45° and 135° of each half turn.[6,7] It has to be highlighted that cancellation angles vary depending on TF size and distance between TF and receiver (microphone or ear), so the obtained data (51° and 130°) refer specifically to the conditions of the experiment described in the Methods section. Furthermore, the maximum amplitudes emitted by the vibrating tuning fork were recorded for 0° and 180°: these angles represent precisely the positioning recognized as best practice in performing the Rinne test, with the TF tines lined up with the axis of the external auditory canal (EAC). This means that during the Rinne test, a change in the angle of the tines relative to the EAC—whether by the patient moving their head or the clinician moving or poorly positioning the tuning fork—will reduce the patient's perception of the amplitude.

The extent of potential differences in sound perception in relation to the TF position was measured in the clinical setup of the experiment. Measurements confirmed differences in sound intensity of the vibrating TF in relation to its position. Results of group A—when measured sound amplitude changed from the recorded maxima (which are related to the 0° and 180° positions, as was proved in the laboratory setup) to the recorded minima (which relate to the cancellation angles determined in the laboratory setup)—ranged from 34.70 to 13.20 dB, with an average decrease of 22.80 dB. When the vibrating TF changed from the ''muting'' position (ie, the cancellation angle at which minimal amplitudes are emitted) to the position at which TF sound amplitude is at maximal level (group B results), the differences in sound amplitude ranged from 9.80 to 23.50 dB, with an average increase of 17.79 dB.

In the first subgroup of the results (group A), the muting effect progressively comes into play as the TF rotates, and this drop in amplitude is added to by the natural decay in sound amplitude over time; meanwhile, in the second subgroup of the results (group B), the increase in amplitude caused by the TF's rotation from an initial ''muted'' position to a ''loud''

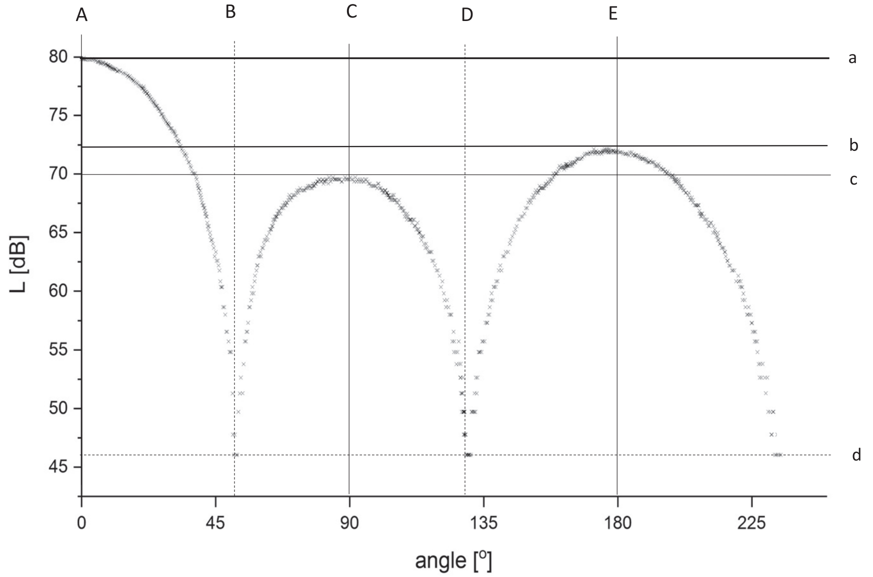

**Figure 4.** Sound amplitude during tuning fork rotation. (A, C, E) Angles of maximum sound amplitudes. (B, D) Angles of minimum sound amplitude. (a-d) Intensities of sound amplitude.

position is counteracted by the loss in amplitude as the soundwave naturally decays, thereby making the difference lower. The extent of the discrepancy is due to the sound decay of the vibrating TF not being linear.[3] The decay rate is not accounted for by a simple calculation based on the time needed to rotate the TF from 0° to 180° and the estimated sound decay ratio. Indeed, according to the principle of energy conservation, the louder the sound produced by the TF, the more quickly it will decay. Thus, regardless of the possible variations in TF size, material, or positioning, this decay should be considered when conducting the Rinne test. Specifically, the TF should be moved from the ''bone'' to the ''ear'' position and vice versa as quickly as possible to minimize the impact of sound decay on the sound amplitude perceived by the patient. In clinical practice, a quick change between ''bone'' and ''ear'' position is thus more important when the TF must be excited to a high amplitude to be heard (eg, when testing patients with significant hearing impairment), as the sound decay rate will be greater in such cases.

The experiment in the laboratory setup was conducted only for a single 360° rotation of the tuning fork with a duration of 9 seconds, giving an estimated sound decay of 0.69 dB/s; this should not be considered a reference but only as information on these specific experimental conditions.

From the clinical perspective, the rotation of the tuning fork applied during the experiment should not be discussed, because the rotation of the TF is not, or should not, be present during the Rinne test. The vibrating TF should be presented to patients in a stable physical position, according to established best practice (ie, the tines should be lined up with the EAC). However, examination conditions may be unstable; for example, the patient moves their head or the person conducting the Rinne test alters the position of the TF during the air conduction evaluation. To establish the potential impact of such undesirable variations in test conditions, therefore, the current experiment aimed to evaluate the amplitude of the sound emitted by the TF at all possible angles of the TF relative to the ear. The constant rotation of the TF in the experiment provided sound intensities changing from loud to quiet and from quiet to loud, showing the potential range of differences through a full rotation of the TF.

The results on sound intensities were subsequently compared to published data regarding Rinne test results. According to Browning[9] and Browning and Swan,[10] the Rinne test can correctly detect conductive hearing impairment of 20 dB or more air-bone gap. The conclusion drawn by Stankiewicz and Mowry[11] was that the Rinne test has no clinical value when the air-bone gap in the tested patient is less than 25 dB. Sheehy et al[12] noted that conductive hearing loss of 15 dB at 512 Hz will reverse the tuning fork test result from positive to negative, and Wilson and Woods[13] presented that the Rinne test has a high degree of accuracy but only with an air-bone gap of greater than 35 dB (note: study in children). Similarly, Crowley and Kaufman[14] used 4 different frequencies to examine 153 ears in adults with conductive hearing loss and showed that an air-bone gap of 15 dB or less yielded a positive Rinne test result, while air-bone gaps above 30 dB yielded a negative result. Even further conclusions were published by Gelfand,[15] who stated that a conductive hearing loss of approximately 40 dB was needed to obtain a negative response (note: tests with masking).

The current study has proved that a change of TF position with respect to the long axis changed the measured sound amplitude through air conduction by a mean value of 17.79 and 22.80 dB for 2 recorded conditions (**Figure 3**). This means, in relation to the published data cited above, that accidental positioning of the vibrating tuning fork within the muting position equal to the cancellation angle or in a position other than ''correct'' one with tines of the TF and axis of the EAC lined up can change the result of Rinne test, increasing negative or equivocal results.

Furthermore, calculations revealed that the risk of false results is highest in the high range of sound amplitude delivered by the vibrating TF, because the difference between maximal and minimal amplitude is the greatest, reaching a maximum level of 34.70 dB. Contrary to that, the lowest change in sound intensity between correct and incorrect (muting) positions of the TF was observed in the low range of TF vibration intensities. The lowest calculated differences in sound amplitude were 9.9 and 13.2 dB (for 2 recorded conditions; **Table 1**), which may not change the Rinne test result as discussed above. Thus, these findings suggest that tests should be conducted in a quiet environment with a vibrating tuning fork emitting as low a sound as possible.

## Conclusions

The reliability of the Rinne test can be considerably impaired by incorrect positioning of the TF next to the ear. Not paying attention to the precise angle at which the tuning fork is held relative to the ear increases the potential for negative or equivocal results, especially when high background noise or patient hearing loss requires that the tuning fork be vigorously excited to obtain high sound amplitudes. Accordingly, positioning the tuning fork with the long axis perpendicular to the external auditory canal and tines lined up with the external auditory canal should be of primary concern during TF clinical tests, which should be conducted in a quiet environment.

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### Author Contributions

**Maciej J. Wrobel**, study concept and design, measurements, literature review, manuscript preparation and submission; **Bogdan F. Bogacz**, laboratory experiments, data processing, figure preparation, manuscript editing.

### Disclosures

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