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Acoustic Reflexes are Common but Not Pervasive: Evidence Using a Diagnostic Middle Ear Analyzer

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Abstract

Objective: To determine whether acoustic reflexes are pervasive (i.e., known with 95 % confidence to be observed in at least 95 % of people) by examining the frequency of occurrence using a friction-fit diagnostic middle ear analyzer.

Design: A group of 285 adult participants with very good hearing sensitivity underwent audiometric and middle ear testing. Acoustic reflexes were tested ipsilaterally and contralaterally in both ears across a range of elicitor frequencies. Two automated methods were used to detect the presence of an acoustic reflex.

Results: There were no conditions in which the proportion of participants exhibiting acoustic reflexes was high enough to be deemed pervasive. Ipsilateral reflexes were more likely to be observed than contralateral reflexes and reflexes were more common at .5 and 1 kHz elicitor frequencies as compared to 2 and 4 kHz elicitor frequencies.

Conclusions: Acoustic reflexes are common among individuals with good hearing. However, acoustic reflexes cannot be considered pervasive and should not be included in damage risk criteria and health hazard assessments for impulsive noise.

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Keywords

Noise; middle ear; acoustic reflex; hearing conservation

INTRODUCTION

The acoustic reflex (AR) has played a role in various methods of assessing the hazards posed by impulsive noises (Ward, 1968), as estimated using damage-risk criteria (DRC). If the AR, or more generally, middle ear muscle contractions (MEMC), are to play a substantial role in DRC, then they must be known to be pervasive (i.e. present in everyone) in the exposed population. It is impossible to confirm a 100 % prevalence in a sampled population. Therefore, the operational definition of a pervasive response is a minimum of 95% confidence of a minimum of 95% prevalence (Patterson et al, 1985). This limit is equivalent to the lower boundary of the 90 % confidence interval for a prevalence proportion that is 0.95 or more. The AR was not determined to be pervasive in a prior study (Flamme et al., 2017), and the current study was conducted to confirm or disconfirm these results with a different study population and measurement instrument.

The AR is an involuntary contraction of the stapedius and/or tensor tympani muscles of the middle ear in response to high-level acoustic stimuli. The middle ear muscle contractions (MEMC) are typically assumed to be bilateral and have the effect of increasing middle ear impedance in the low frequencies. The afferent limb of the reflex is mediated over cranial nerve VIII terminating in the cochlear nucleus, while the efferent limb synapses onto the stapedius and tensor tympani muscles via cranial nerves VII and V respectively (Mukerji, Windsor and Lee, 2010). However, the central neural circuitry that lies between these two limbs is complex and not thoroughly understood (Mukerji et al, 2010). The middle ear muscles are also known to respond to non-acoustic stimuli (Djupesland, 1964; Fee, Dirks, & Morgan, 1975) and in association with behaviors such as eye closure, vocalization and swallowing (Simmons, 1964). The physiologic and/or evolutionary purposes of the AR are unclear, though a number of hypotheses have been suggested, including intensity control of external or internally generated sound (Borg, Counter & Rosler, 1984), enhancing sensitivity to high frequency sounds (Simmons, 1964) and functioning as a vestige of muscle activity required for jaw stability in early mammals/amphibians during mastication (Manley, 2010). Others have proposed that the AR conferred a survival advantage for predators and prey by preserving localization cues during pursuit or flight (Lawrence, 1965).

Factors such as age (Hodges & Ruth, 1987; Hall, 1982), attention (Durrant & Shallop, 1969; Robinette & Snyder, 1982), middle ear abnormalities (Jerger et al, 1974a; Nozza et al, 1992), hearing status (Gelfand, Piper & Silman, 1983), and gender (Flamme et al, 2017; Hall, 1982) have been shown to influence the likelihood of observing an AR. For example, an AR is more likely to be observed in females as compared to males (Flamme et al, 2017), young adults as compared to older adults (Flamme et al, 2017; Silman, 1979), and in individuals with normal hearing as compared to individuals with hearing impairments (Silman, Popelka & Gelfand, 1978; Jerger, Jerger & Mauldin, 1972).

The AR is typically measured indirectly by observing changes to a probe signal presented in the ear canal (Metz, 1952). Changes in middle ear impedance alter the ear's response to a probe signal. Conventional AR measurements with adults use a 226 Hz probe tone, which is used because, under standard atmospheric conditions, a change of one milliliter (ml) of effective volume corresponds to a change of one millimho change in admittance. An AR is deemed present when the change associated with the elicitor exceeds a specified amount, typically 0.02 ml for many research applications. Clinical assessments of reflexes are frequently based on the morphology of the impedance change over time rather than a specific change in admittance (Gelfand, 2009). An individual's acoustic reflex threshold is the lowest elicitor level (dB HL) at which an impedance change is observed and repeatable. Acoustic reflexes have been used clinically as an indicator of stimulus audibility (Silman et al, 1978), retrocochlear integrity (Gelfand, 2009) and middle ear status (ASHA, 1990).

Many previous studies attempting to determine the rate of occurrence of the AR (Gelfand & Piper, 1984; Silman, 1979; Gelfand et al, 1983) have not focused on estimating its prevalence within the population. Instead, these studies focused on use of the AR in clinical diagnosis. As a result, AR rates were often reported in terms of ears rather than people. The use of individual ears is acceptable for clinical purposes, where ear-specific diagnoses are required. However, DRC are applied to the whole person, so ear-specific rates do not apply. Additionally, many such studies (Gelfand et al, 1983; Gelfand & Piper, 1984; Gates et al, 1990; Popelka, 1981) replaced missing values with values one audiometric step above the highest presentation level if no AR was observed. This strategy was adequate for the purposes of those studies, but it precludes accurate estimates of the prevalence of AR in the general population.

Recently, Flamme et al (2017) used data from the National Health and Nutrition Examination Survey (NHANES) to estimate the AR prevalence. The NHANES is a large-scale survey of the civilian, non-institutionalized U.S. population. Data from NHANES can be used to examine health trends across the U.S. in areas such environmental exposure, diabetes, obesity, vision, and hearing (CDC/NCHS, 2017a). The NHANES includes audiometric testing, including audiometry, tympanometry, and acoustic reflexes. Acoustic reflex and tympanometry data were collected using a device with a handheld probe (Earscan, Micro Audiometrics Corp., Murphy, NC), meaning the ear probe was held in place by audiologist-trained technicians during testing. The use of a friction-fit probe reduces the probability that probe movement from the tester could influence error rates, which is why the friction-fit probe was used in the current study.

Acoustic reflexes were measured ipsilaterally at 1 and 2 kHz for both ears at an intensity of 105 dB SPL (105 dB HL for 1 kHz and 102 dB HL for 2 kHz). See Flamme et al (2017) for a thorough explanation of the settings in which these assessments were conducted. A sample of more than 15,000 participants was drawn from the NHANES database. Given the size of the dataset, two different automated detection algorithms were used to identify the presence/absence of an AR and prevalence was estimated overall and with consideration of factors such as age, hearing status and gender. The authors were unable to identify any groups within the population where the AR prevalence was pervasive (i.e. the lower bound of the

90% confidence interval of the prevalence estimate exceeded 95%), even in subgroups of the population with the greatest likelihood of an AR.

Flamme et al (2017) estimated the prevalence of AR in three participant groups: all participants, participants aged 18–30, and participants aged 18–30 with good hearing, defined as H-1 hearing status (Department of the Army, 2011). Previous studies have shown that individuals who are younger (Hodges & Ruth, 1987; Hall, 1982) and who have better hearing (Silman et al, 1978) exhibit a higher proportion of present AR, which was the case with group three (86.9%) compared to groups one and two (74.6% and 85.3%, respectively). However, even in individuals with the best hearing and at the youngest age range, the AR was not pervasive. Due to the lack of a pervasive AR in any subpopulation, Flamme et al (2017) determined that DRC for impulsive noises should not include AR.

One potential limitation of the Flamme et al (2017) results was that the NHANES study used a test device with a handheld probe. Unintended movement of the probe either during or after the stimulus presentation could compromise the quality of the reflex recordings. Movement artifact during the time window when a reflex is expected could lead to an erroneous reflex identification when one was not present (i.e. a false positive response). Alternatively, movement artifact when a stable baseline is expected could lead to erroneously missing an actual reflex (i.e. a false negative response). The latter would lead to underestimates of AR prevalence. Flamme et al (2017) addressed this issue by examining the variance distribution of the baseline segments of all AR traces. Even after eliminating the noisiest half of the traces, where false negative responses are most likely to occur, the AR prevalence still did not meet the pervasiveness criterion in any study group.

The goal of the present study was (1) to determine if using a diagnostic middle ear analyzer with a friction-fit probe yields a different probability of observing an AR than was observed previously, and (2) to determine whether the results suggest a different decision than Flamme et al (2017) with respect to AR pervasiveness.

METHODS

Participants

The participant pool for the current study was drawn from a larger multi-visit study designed to examine MEMC under a variety of experimental conditions. During the initial visit of the larger study, participants completed questionnaires related to hearing health and noise exposure, underwent standard clinical audiological procedures including otoscopy, audiometric testing, and middle ear assessment, participated in a brief screening of cranial nerves V and VII and completed a short pupillary conditioning experiment. The main goal of this initial visit was to determine if participants met the eligibility criteria for the remaining part of the larger study.

The data used in the current study included results from all participants who completed this first visit and for whom middle ear assessments were available. No effort was made to exclude participants based on audiometric, otoscopic, cranial nerve screening or questionnaire results. A total of 285 participants ranging in age from 18–68 years were used for this study. The median age of the participants in the study was 21 years old (interquartile range: 20 to 23 years). The sample included 199 (70%) females and 86 males. Both the young age of participants and the large number of female participants likely resulted from the location participants were recruited. The fields of study at the College of Health and Human Services (CHHS) at Western Michigan University (WMU) are primarily dominated by young adult females.

Participants were recruited using informational flyers distributed throughout the CHHS building at WMU and surrounding areas in Kalamazoo, MI and through word-of-mouth from previous participants. This study was reviewed and approved by the Human Subjects Institutional Review Board of WMU and the Human Research Protection Office of the U.S. Army Medical Research and Materiel Command.

Instrumentation

Middle ear analyzer—The Interacoustics Titan Middle Ear Analyzer was used to collect the following impedance measures: tympanometry, wideband absorbance, wideband tympanometry, AR, and acoustic reflex decay. Only the AR results will be discussed in the current study. The probe on the Titan is a friction-fit probe, which remains in the ear without being held by the tester. The AR traces were obtained using pure-tone elicitors at 0.5, 1, 2, and 4 kHz both ipsilaterally and contralaterally using a conventional 226 Hz probe tone. The elicitor duration was over 700 ms. The probe began in the right ear for all participants, followed by the left ear. Therefore, measures of AR were obtained in the following order: right ipsilateral, left contralateral, left ipsilateral, right contralateral.

Elicitor tones were presented in ascending 5-dB steps between 80 dB HL and 100 dB HL. The instrument was configured to discontinue an ascending run once an impedance change exceeding 0.05 ml was detected on two consecutive trials. The impedance change of 0.05 ml was used instead of the clinically accepted change of 0.02 ml for this study to observe the growth of the reflex with increased elicitor intensity. Raw traces of middle ear impedance were exported for correlational analyses in the MATLAB (Mathworks, Inc., Natick MA) software environment.

Audiometric Research Tool—Pure tone audiometric thresholds were obtained using the Nelson Acoustics Audiometric Research Tool, which uses National Instruments PXI-4461 dynamic signal analyzer modules for signal generation and data acquisition functions. The dynamic signal analyzer modules were housed within a National Instruments PXI-1082 chassis and controlled using a National Instruments PXIe-8133 embedded controller. The software was configured to determine thresholds according to the modified Hughson-Westlake procedure (Carhart & Jerger, 1959) and retains the complete stimulus presentation history that led to threshold determination. Pure tone air conduction thresholds were obtained bilaterally at octave frequencies between 0.125 to 8 kHz plus the inter-octave frequencies of 3 and 6 kHz using Sennheiser HDA-200 headphones. Bone conduction threshold testing was conducted at 0.5, 1, 2, and 4 kHz using a RadioEar B-71 transducer placed on the forehead. Stimulus levels were checked twice daily during the data collection period using the IEC 60318–1 flat plate fixture for air conduction. Bone conduction stimuli were calibrated quarterly using the Brüel and Kjær 4930 artificial mastoid.

Procedure

During a participant's first visit for the larger study, the data for this retrospective study was obtained. Participants completed a questionnaire which included questions on history of tinnitus, noise exposure (occupational noise, leisure noise, and firearm use), facial nerve disorders, such as Bell's palsy, and concussions. The questionnaire was followed by a video-otoscopic examination of the external ear and pure tone threshold audiometry. Participants were given an opportunity for a short break followed by a cranial nerves screening. The final two sets of measures taken during this visit were middle ear assessment and a test of the participant's pupillary response to light and sound.

The data collection procedure was controlled using a custom MATLAB script that controlled the data acquisition process (i.e. otoscopy, cranial nerve testing and pupil conditioning) and automatically launched proprietary software (i.e. audiometry and middle ear assessment) during protocol execution. The visit that included the procedures used in this paper took approximately one hour after the participant provided informed consent to participate.

Data Processing/Analysis

The audiometric data collected for each participant were classified into audiometric configurations described in Ciletti & Flamme (2008), see Table 1. Each configuration is labelled with a letter followed by a number. The letter represents the thresholds in the low frequencies (0.5 to 2 kHz), and the number represents the threshold of the worst frequency above 2 kHz (Ciletti & Flamme, 2008). Of the 285 participants included in this study, 261 (92%) participants had audiometric thresholds that were best described by the A11 configuration. The thresholds in the A11 configuration represented the group with the best hearing sensitivity in the NHANES dataset used by Ciletti & Flamme (2008). This configuration was characterized by bilateral symmetry and mean pure tone thresholds of 10 dB HL or less between the stimulus frequencies of 0.5 to 8 kHz, with the exception of a mean threshold of 11 dB HL at 6 kHz. Following A11, A19 and A22 were the next most frequent configurations and each accounted for approximately 2 % of the sample (i.e., A11, A19, and A22 accounted for approximately 96 % of the total sample). These configurations are very similar, but were identified separately for men and women in the Ciletti & Flamme study.

Reflex Detection Methods

Analyses were performed on all reflex traces collected. Two methods of reflex detection were developed and implemented using custom written MATLAB scripts. These methods are similar, but not identical to the *Frequentist* and *Bayesian/Kalman* methods described in Flamme et al (2017). The first method, referred to as the conventional method, identifies a reflex as present if the maximum change in the reflex trace is greater than 0.02 ml, based on the underlying assumption that this much change would be infrequent in the absence of an MEMC. One disadvantage of the conventional method is that the morphology of the reflex is not taken into consideration. The second method, referred to as the correlational method, identifies a reflex as present if the correlation between that trace and one of a set of reflex prototypes exceeds a correlation coefficient "cut-point". This procedure required a number of analysis steps.

Prototype Determination

The prototypical shapes were selected based on the presence of a stimulus-linked change in the trace. All traces collected for each frequency/laterality combination were viewed on the same figure, showing reflex growth and morphology patterns. Similar stimulus-linked changes across sampled traces were considered candidates for prototypes, and the 11 original prototypes were selected from emblematic examples in the sample and to maximize the differences among the prototypes. Further analyses of the prototypes determined that four prototypes were highly correlated (e.g., > 0.93) to at least one of the remaining prototypes, and therefore were considered redundant. The seven remaining prototypes (Figure 1) were used for the remaining analyses.

Cut-point Determination

In order to determine correlation cut-point, 406 reflex traces were randomly selected from the dataset. Four authors (KM, GF, ST, KD) independently viewed each trace and made binary judgments on the presence/absence of a stimulus-linked change in impedance (i.e., an AR). Presence of a reflex was judged only on the morphology of the reflex. The time axis scaling remained so that the judge could confirm that the reflex was time-linked to the elicitor.

Traces in which all four judges agreed that a reflex was present were classified as true reflexes. All other traces, including those where only 2 or 3 of the judges agreed, were labeled as no reflex present. Interrater agreement, as represented by Cohen's kappa statistic was (κ=.826), which is considered excellent by conventional interpretation guidelines (Lindis & Koch, 1977). The binary indicators for all 406 traces were then used to complete a Receiver Operating Characteristic (ROC) curve, which produced the sensitivity and specificity of this identification method at various correlation cut-points. The area under the ROC curve for this analysis was 0.96, and sensitivity and specificity was maximized at a cut-point of 0.8617.

Statistical Analysis

Proportions of AR observations and 90 % confidence intervals and analyses of NHANES data were calculated using the Stata software package (StataCorp, College Station, TX). The 90 % confidence interval was used because the lower bound of the 90 % confidence interval represents the point above which 95 % of observations would be expected to fall under infinite repeated random sampling of a population. Thus, a lower bound of the 90 % confidence interval that is greater than a proportion of 0.95 would indicate greater than 95 % certainty that 95 % of the sample would exhibit an AR. Analyses of NHANES were conducted using complex sample variables (e.g., sample weighting, clusters, and population sampling units) in accordance with guidance from the CDC/National Center for Health Statistics (CDC/NCHS, 2017b).

RESULTS

Proportions of Acoustic Reflexes

The results for the correlational detection method are shown in Table 2. Each ear was analyzed separately, for each elicitor frequency and each laterality. The bilateral category represents the proportion of participants with present AR at the elicitor frequency in both ears. An individual is less likely to have an AR in both ears than in only one, and therefore, the proportions of AR are lower for the bilateral category than for left or right ear separately. Each category also includes "1 or 2 kHz" in the ipsilateral condition for comparison with results from the NHANES study (Flamme et al, 2017), analyzed using the same criteria. We have calculated the proportion of participants with a reflex present at either 1 or 2 kHz for the left ear, right ear, and in both ears for the ipsilateral condition only. This proportion will be higher than either 1 or 2 kHz on its own. Similar results for the conventional detection method are shown in Table 3. As discussed previously, an AR is considered pervasive when the lower bounds of the 90% confidence interval exceed 0.95. We were unable to find a category, using either detection method, that met this criterion. It is, however, important to notice two trends in these results. First, the proportion of AR was lower for the contralateral AR than for the ipsilateral AR at every elicitor frequency. This trend was found with both detection methods. The difference (as a percentage) between ipsilateral and contralateral AR ranges from 6.7% to 20.4% (mean: 11.9%, SD: 3.87%).

Another important trend in these results is that the proportions of AR at 0.5 and 1 kHz were higher than those at 2 and 4 kHz. To quantify this difference, we found the average of the proportions at 0.5 and 1 kHz (referred to as 5–1 average) and at 2 and 4 kHz (2–4 average) for each condition. The 2–4 average was subtracted from the 5–1 average to calculate the difference (presented as a percentage). The mean differences were as follows: 4.3% (SD: 0.43%) for ipsilateral, correlational method; 5.55% (SD:1.90%) for contralateral, correlational method; 8.28% (SD:1.81%) for ipsilateral, conventional method; 2.55% (SD: 0.17%) for contralateral, conventional method.

Comparison across groups

To compare the results from the current study to the results presented in Flamme et al (2017), four participant groups were further analyzed to determine the proportion of individuals in each group with an AR at 1 or 2 kHz. The four participant groups, based on age and audiometric results, included: any age and any audiogram configuration (all participants), any age and an audiogram best described by the A11 configuration (Ciletti & Flamme, 2008), individuals 18–30 years old with any audiometric configuration, and individuals 18–30 years old with an audiogram best described by the A11 configuration. The numbers of participants in each group, as well as the proportions of individuals in each group with an AR at 1 or 2 kHz in both ears and the 90% confidence intervals for both detection methods are shown in Table 4. The results represented in Table 4 show that the AR is very common in these participant subgroups. The proportion of AR was above 90% in all participant groups for both detection methods. However, the lower bounds of the 90% confidence intervals did not exceed 0.95 for any of the groups using either detection method. Even in the fourth group, which includes individuals who are young (18–30 years) and have very good hearing (hearing levels best described by the A11 configuration), the AR rates did not meet the criterion for pervasiveness. We confirmed the results of Flamme et al (2017) which concluded that the AR was very common, but was not pervasive.

Comparison to NHANES

The mean thresholds of individuals with audiometric configurations best described by A11 (Ciletti & Flamme, 2008) for the current study were typically better than the thresholds used originally to define the A11 audiometric configuration. For example, the threshold at 1 kHz as described by A11 is 4 dB HL, but the mean threshold at 1 kHz for the current study was 0 dB HL for both the left and right ears. The mean thresholds for the current study and the A11 configuration are shown in Figure 2. The mean thresholds for individuals with thresholds best described by the A11 audiometric configuration were better than the A11 audiometric configuration at all frequencies (0.5 kHz to 8 kHz). In order to provide a more precise comparison, the NHANES data used in Flamme et al (2017) were re-analyzed using only participants whose thresholds fell within the interquartile range (IQR) of individuals best described by A11 in the current study. The same analysis and reflex detection methods described in Flamme et al (2017) were used.

The proportion of bilateral AR reported in Flamme et al (2017) for the youngest population (aged 18–30 years) with the best hearing (audiograms best described by A11) using either detection method from that study was 0.91 with a 90% confidence interval from 0.89 to 0.92. Using only NHANES participants with audiograms within the IQR of the current study, the proportion increased to 0.94 with a 90% confidence interval from 0.91 to 0.98. These highly screened results from NHANES are most comparable to participant group 4 in Table 4, where the proportions in the current study matched the highly screened NHANES group within one percent, and continue to demonstrate lack of AR pervasiveness.

DISCUSSION AND IMPLICATIONS

Summary

The current study was undertaken to determine whether the proportions of acoustic reflexes observed in a laboratory study using a diagnostic middle ear analyzer with a friction-fit probe were similar to the nationally-representative (NHANES) results obtained using a screening device and handheld probe. The results obtained in the current study confirm the nationally-representative results of Flamme et al (2017) and reaffirm the conclusion that acoustic reflexes are common, but not pervasive. In spite of the large sample of young participants with excellent hearing, we remain unable to find a subpopulation in which AR are pervasive.

It is possible that cases of absent acoustic reflexes could be associated with reductions to the numbers of synapses the inner hair cell and auditory nerve fibers, which can be described as cochlear neuropathy. Recent work with mouse models (Valero et al. 2016) suggests that neuropathy induced by noise exposure might reduce or degenerate synapses to auditory nerve fibers and thus disturbing acoustic reflexes. It is not clear whether this phenomenon was a large contributor to the results of this study or if cochlear neuropathy might explain

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differences in the probabilities of responses across frequency and stimulus-probe configurations. However, the results of Valero et al. (2016) and other related work are relevant to the issue of reliance on AR by DRC for impulsive noise.

Biases and Limitations

The proportions of responses found in the current study were considerably higher than would be observed in the general population. Prior studies (Flamme et al, 2017; Hall, 1982; Hodges & Ruth, 1987) have shown that the probability of reflex detection declines with a decrease in hearing sensitivity, male gender, and increasing age. It is also possible that the proportion of individuals exhibiting AR would have been higher if broadband elicitors (e.g., white or pink noise) had been used. We elected not to evaluate broadband noise stimuli for this component of the study because broadband elicitors were included in other aspects of the overall project and because the main purpose of these analyses was to make a comparison to the tonal elicitor results described in Flamme et al. (2017).

The median age of participants was 21 years old (interquartile range: 20 to 23 years) and 70 % of the individuals were female, which both lead to what is likely an overestimate of the proportion of AR seen in the general population. If the gender distribution of the participants had been more equal and/or the average age of participants had been higher, it is likely that the proportions of AR observed would decrease (Flamme et al, 2017; Hall, 1982).

It is important to note that the results of the current study apply to stimulus durations that are considerably longer and at lower levels than the impulsive sounds addressed by a DRC for impulsive noise. The observation of an AR for a long-duration signal does not necessarily imply that short-duration signals like gunshots will also elicit an AR among people with robust AR for long-duration signals. In this study, presentations were not made at higher levels because the levels tested here were similar to those used in the prior study and to ensure the safety of the volunteer research participants (Hunter et al., 1999; Schairer, et al., 2007), who were exposed to high-level signals in other study procedures. It is also important to note that responses at higher levels could be more likely to elicit middle ear muscle contractions through alternate neural pathways (e.g., eye blinks), which are very likely to produce middle ear muscle contractions (Tasko, et al., 2017).

Suggestions for future research

The current study and Flamme et al (2017) examined only the AR at 1 and 2 kHz in relation to the pervasiveness of the AR. This was a limitation of the NHANES data set, as those were the only two frequencies obtained. However, as our results showed, AR at 0.5 and 1 kHz were more common than AR at 2 and 4 kHz. Therefore, a more comprehensive study including all four test frequencies could lead to a different decision about inclusion in DRC and may be worthwhile to explore if the investigators in that study manage the capitalization on chance across multiple observations. One complication to such a study, however, is that the inclusion of AR in a DRC would involve the generalization of results obtained with non-impulsive sounds to impulsive sounds. In the current study, we judged a person as having an AR if reflexes were observed in at least one of the two elicitor frequencies under consideration, which represents as little as 50 % of the elicitors presented. In such a case, the response observed to one elicitor stimulus was not shown to generalize to a similar stimulus of equal duration. The finding of AR for only one elicitor stimulus confirms the integrity of some portions of the reflex arc, but it is not sufficient evidence to ensure that this arc will be activated by a substantially different stimulus such as an impulse.

The finding that the proportions of AR were lower for the contralateral condition than for the ipsilateral condition suggests that bilateral contractions are not sufficiently dependable to justify their inclusion in DRC for impulsive noise, even among individuals with very good hearing sensitivity. This finding is perhaps an outcropping of the impressions of Mukerji et al (2010), who expressed the position that the neural pathways triggering the MEMC are more complex than suggested by conventional wisdom. Future research surveying the conditions leading to MEMC could augment neurophysiological studies of the anatomy and physiology of the nuclei involved in the MEMC.

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DECLARATION OF INTEREST

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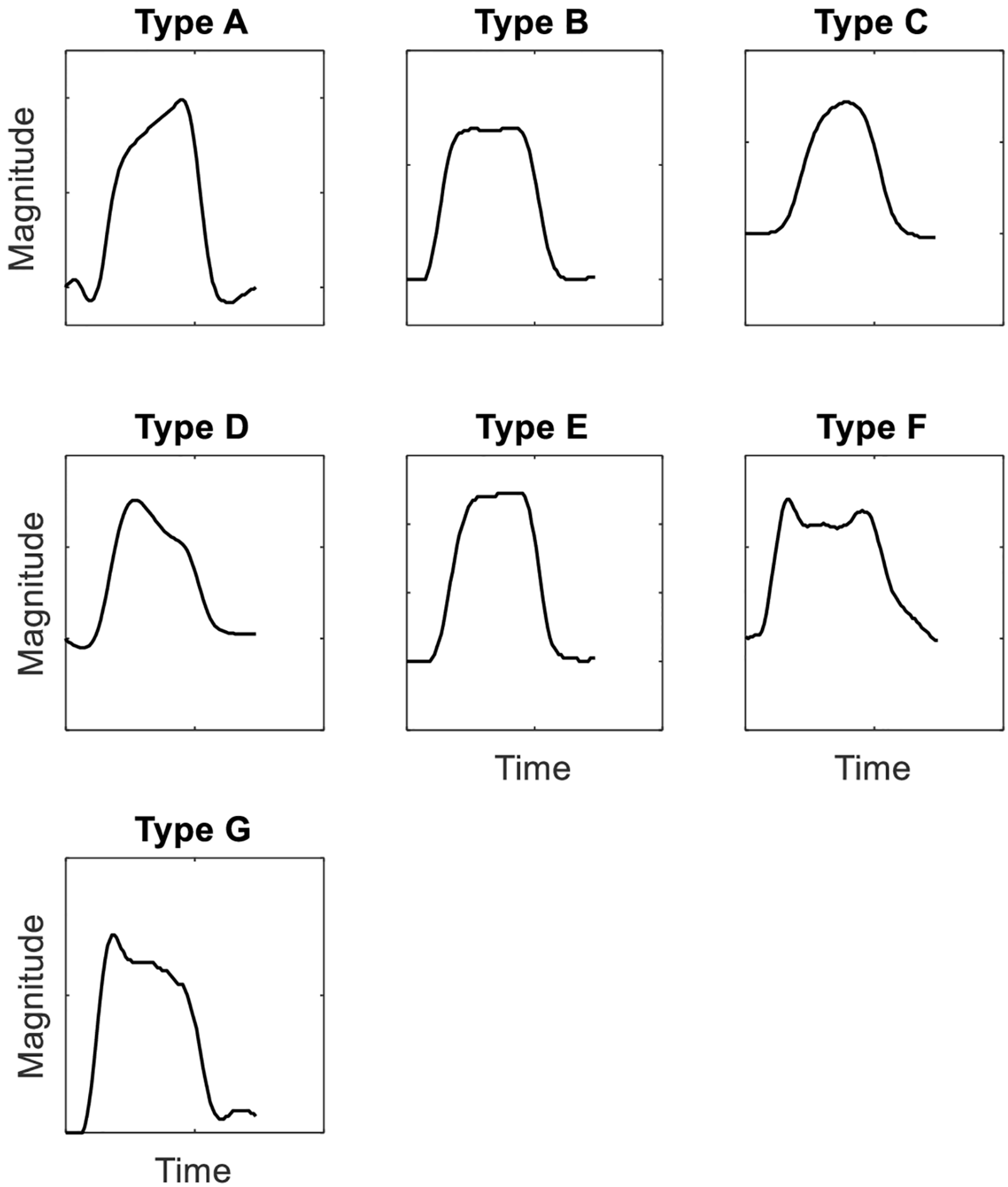

Figure 1.

Prototypes used for correlation method of AR detection. Each plot represents time on the horizontal axis and reflex magnitude on the vertical axis. Note that a change in the upward direction represents a decrease in admittance. Prototypes were identified visually during review of AR traces, and the traces plotted in this figure were taken from raw traces.

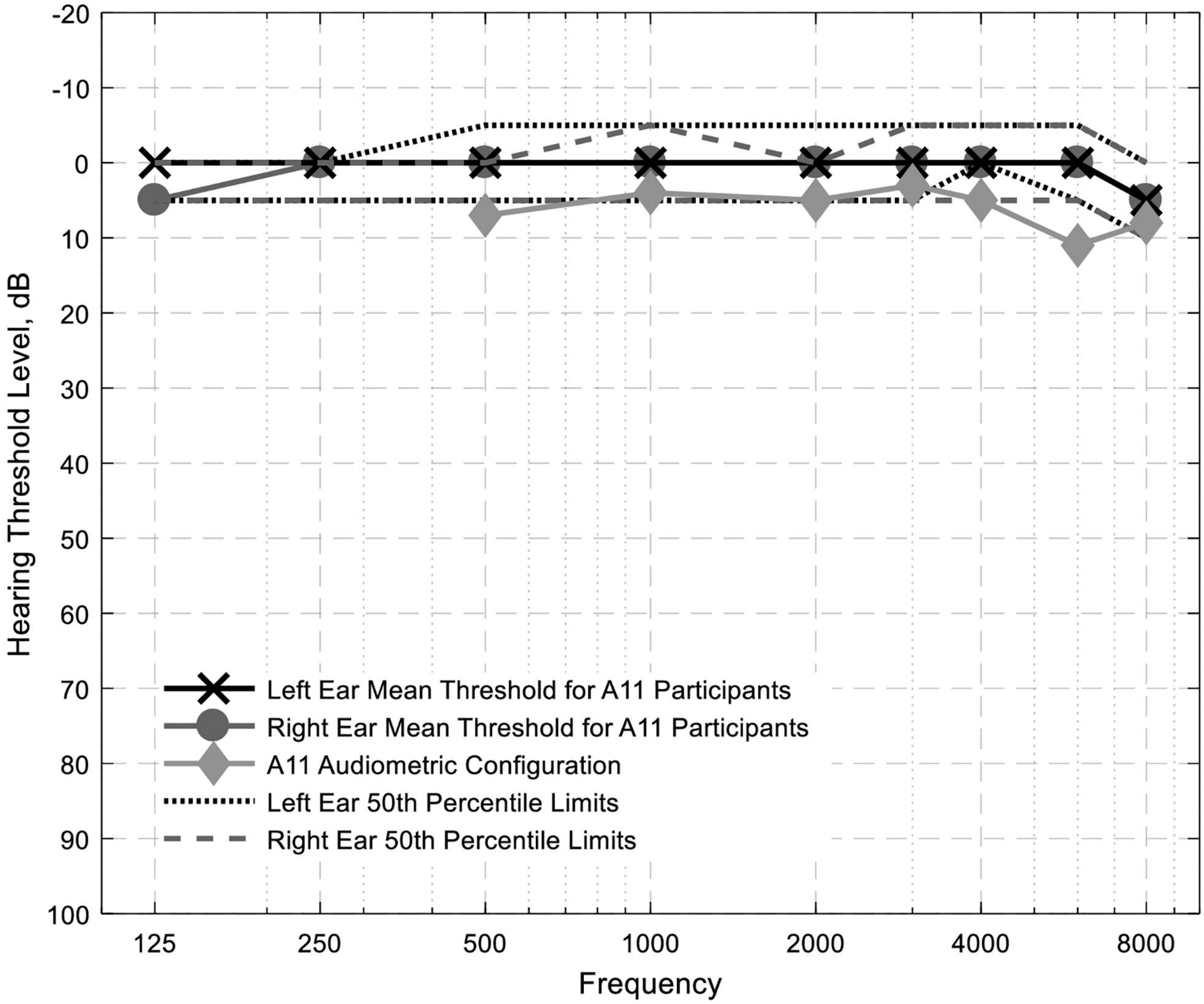

Figure 2.
Mean thresholds for the participant group in the current study. The light gray line with filled diamonds represents the A11 audiometric configuration.

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Table 1.

Definitions of selected audiometric configurations from Ciletti & Flamme (2008). Tabled values represent mean audiometric thresholds (dB HTL) for each configuration.

Configuration	Gender	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
A11	Both	**7**	**4**	**5**	**3**	**5**	**11**	**8**
A19	Male	**10**	**8**	**8**	**10**	**14**	**19**	**18**
A22	Female	**12**	**9**	**9**	**10**	**13**	**22**	**19**

Table 2.

Proportions of acoustic reflexes determined using the correlational detection method. The low boundary of the confidence interval is presented in boldface because it is the key outcome for this study. Note that the 90 % confidence intervals for the "1 or 2 kHz" rows were calculated for a single proportion rather than adjusting for the combination of two proportions, which would expand the range between confidence limits.

	Ipsilateral			**Contralateral**		
		90% confidence limits			*90% confidence limits*	
Stimulus Frequency	***Proportion***	***Low***	***High***	***Proportion***	***Low***	***High***
Left Ear						
500 Hz	0.92	**0.89**	0.94	0.83	**0.79**	0.87
1000 Hz	0.94	**0.91**	0.96	0.86	**0.82**	0.89
2000 Hz	0.89	**0.85**	0.92	0.79	**0.75**	0.83
4000 Hz	0.90	**0.86**	0.92	0.75	**0.71**	0.79
1 or 2 kHz	0.96	**0.94**	0.98	–	**–**	–
Right Ear						
500 Hz	0.92	**0.88**	0.94	0.85	**0.81**	0.88
1000 Hz	0.93	**0.90**	0.95	0.82	**0.78**	0.86
2000 Hz	0.88	**0.85**	0.91	0.80	**0.76**	0.84
4000 Hz	0.87	**0.84**	0.90	0.80	**0.75**	0.83
1 or 2 kHz	0.94	**0.91**	0.96	–	**–**	–
Bilateral						
500 Hz	0.86	**0.83**	0.89	0.76	**0.72**	0.80
1000 Hz	0.89	**0.85**	0.92	0.76	**0.72**	0.80
2000 Hz	0.83	**0.79**	0.87	0.72	**0.67**	0.76
4000 Hz	0.83	**0.79**	0.86	0.69	**0.64**	0.73
1 or 2 kHz	0.92	**0.89**	0.94	–	**–**	–

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Table 3.

Proportions of acoustic reflexes determined using the conventional (0.02 ml change) method. Other details are similar to Table 2.

	Ipsilateral			Contralateral		
		90% confidence limits			90% confidence limits	
Stimulus Frequency	***Proportion***	***Low***	***High***	***Proportion***	***Low***	***High***
Left Ear						
500 Hz	0.96	**0.93**	0.97	0.80	**0.76**	0.84
1000 Hz	0.95	**0.93**	0.97	0.81	**0.77**	0.84
2000 Hz	0.87	**0.83**	0.90	0.79	**0.74**	0.82
4000 Hz	0.87	**0.84**	0.90	0.77	**0.73**	0.81
1 or 2 kHz	0.97	**0.94**	0.98	–	**–**	–
Right Ear						
500 Hz	0.94	**0.92**	0.96	0.81	**0.77**	0.85
1000 Hz	0.94	**0.92**	0.96	0.79	**0.74**	0.82
2000 Hz	0.88	**0.85**	0.91	0.78	**0.74**	0.82
4000 Hz	0.88	**0.84**	0.91	0.77	**0.73**	0.81
1 or 2 kHz	0.95	**0.93**	0.97	–	**–**	–
Bilateral						
500 Hz	0.92	**0.89**	0.94	0.72	**0.67**	0.76
1000 Hz	0.91	**0.88**	0.93	0.71	**0.66**	0.75
2000 Hz	0.81	**0.77**	0.85	0.69	**0.64**	0.73
4000 Hz	0.82	**0.78**	0.85	0.68	**0.63**	0.73
1 or 2 kHz	0.93	**0.90**	0.95	–	**–**	–

Table 4.

Proportion of bilateral acoustic reflexes (at 1 kHz or 2 kHz) by participant group and detection approach. Other details are similar to Table 2.

		Correlational			**Conventional**		
			90% confidence interval limits			***90% confidence interval limits***	
	n	***Proportion***	***Low***	***High***	***Proportion***	***Low***	***High***
Group 1:							
Any Age + Any Audiogram	285	0.92	**0.89**	0.94	0.93	**0.90**	0.95
Group 2:							
Any Age + A11 audiogram	261	0.94	**0.91**	0.96	0.94	**0.91**	0.96
Group 3:							
18–30 y.o. + Any audiogram	245	0.92	**0.89**	0.95	0.93	**0.89**	0.95
Group 4:							
18–30 y.o. + A11 audiogram	238	0.95	**0.92**	0.97	0.94	**0.91**	0.96