Acoustic reflexes: Should we be paying more attention?

Acoustic reflexes: Should we be paying more attention?

Garreth Prendergast
Tanvi S. Sathe
Antje Heinrich
Kevin J. Munro

Abstract

OBJECTIVE: The clinical audiology test battery often involves playing physically simple sounds with questionable ecological value to the listener. In this technical report, we revisit how valid this approach is using an automated, involuntary auditory response; the acoustic reflex threshold (ART). DESIGN: The ART was estimated four times in each individual in a quasi-random ordering of task conditions. The baseline condition (referred to as *Neutral)* measured the ART following standard clinical practice. Three experimental conditions were then used in which a secondary task was performed whilst the reflex was measured; *Auditory attention*, *auditory distraction* and *visual distraction* tasks. STUDY SAMPLE: Thirty-eight participants (27 males) with a mean age of 23 years were tested. All participants were audiometrically healthy RESULTS: The ART was elevated when a visual task was performed at the same time as the measurements were taken. Performing an auditory task had no effect on the measured reflex threshold. CONCLUSIONS: These data indicate that simple audiometric measures that are widely used in clinic, can be affected by central, non-auditory processes even in healthy, normal-hearing volunteers. It is our view that considering the role of cognition and attention on auditory responses will become ever more important in the coming years.

Introduction

The acoustic reflex (AR) can be used in clinical settings as a screen for retrocochlear lesions, and to confirm suspected conductive hearing losses (Prasher & Cohen, 1993). Being a reflex, it is automatic and occurs without the listener needing to make any decision or overtly indicate a response. A loud sound, the elicitor, is played into one ear and this causes the stapedius muscle to contract and stiffen the ossicular chain in both ears, which reduces the amount of energy that is transduced from the outer ear to the inner ear (Gelfand, 2009). These changes are frequency-dependent and so the spectral content of the elicitor determines the nature of changes in energy transduction by the middle ear.

Patients are instructed to sit still and ignore the sounds heard, but, it has long been known that acoustic reflex thresholds (ARTs) are modulated when performing a secondary task, with elevated ARTs and diminished AR strength when auditory, visual and arithmetic tasks are performed concurrent with measuring reflexes (Bell, 1966; Durrant & Shallop 1969). AR strength is typically defined as supra-threshold growth, and so diminished AR strength is observed as a reduction in this supra-threshold growth function. Klockhoff (1961), Bell (1966) and Durrant and Shallop (1969) all investigated the effect of a number of different secondary tasks, including auditory and non-auditory tasks of varying complexity, on acoustic reflexes. They, found that when performing a secondary task the ARTs were elevated. This change in

ART was primarily driven by whether a secondary task was being performed, rather than the specific modality (auditory or visual) or complexity (i.e. reading from a newspaper or counting backwards in 7s from 100) of the secondary task.

Conversely, Cleaver (1974) demonstrated that the reflex strength was increased when a person closed their eyes. Robinette & Snyder (1982) performed a systematic investigation of how occular muscle tension interacts with measurements of the AR by using conditions of light and darkened rooms in conjunction with the eyes being closed tightly, softly, or by using a visual task stimulus. Closure of the eyes resulted in an enhanced AR (both lower ARTs and increased growth functions), with voluntary muscle tension from tight closure resulting in a greater enhancement. Both passive and active visual tasks, a number manipulation task and vibrotactile stimulation all resulted in suppression of the AR. These enhancements and suppressions of the AR were expressed as both reduced suprathreshold amplitude and elevated thresholds. It seems clear that whilst the perceptual tasks described previously resulted in a reduction in AR strength, there are also physiological mechanisms which result in muscle movement enhancing the AR (Gruters et al., 2018; Tasko et al., 2022). It may therefore be important to understand how these competing mechanisms function in both the clinic and the real world.

Though the AR is a diagnostic tool in clinic, its evolutionary significance is unknown. Typically it is thought to be protective; to attenuate the amount of high-intensity energy, and perhaps internally generated sound, transmitted through the inner ear (Brask, 1979; Borg et al., 1984). But this protective element is only obtained to transient loud sounds, not sustained ones. There is much we are still learning about the mechanics of the middle ear (Ugarteburu et al., 2022), and it is therefore difficult to predict what mechanisms lead to the AR being affected by these central, possibly cognitive factors. There may, therefore, be value in considering the specific instructions given to participants when performing routine, objective auditory assessments. There are also potentially wider implications for the role of attention across the whole audiological test battery (Nixon et al., 2019).

The primary research aim was to investigate how secondary tasks, involving some level of cognitive control in either the auditory or non-auditory domain, affect ARTs. Based on the reviewed evidence, the hypothesis was that both auditory and visual tasks will result in an increase in ART. Secondary, exploratory hypotheses focussed on whether the visual task resulted in a larger change in ART (as reported by Bell, 1966) and whether there is a difference between the two auditory tasks; described as attention and distraction depending on whether the listeners' attention is directed toward or away from the sounds used to elicit the reflex.

Methods

Participants

A total of 38 participants (27 males) with a mean age of 23 years (S.D. 4 years) were tested. The sample size was chosen based on work within our laboratory which demonstrated that the variability of ARTs measured two hours apart was on average 1 dB (S.D. ± 1.6) and 1.1 dB (S.D. ± 1.5) for a 1000 Hz tonal elicitor and broadband noise elicitor, respectively. An a priori power analysis showed a minimum of 34 participants would allow detection of a 2 dB shift in threshold (assuming a S.D. ±f 4 dB) with 80% power and a two-tailed alpha of 5%. An additional ~15% were recruited to allow for attrition, given the total cohort size of 38. All participants provided informed, written consent and the study protocol was approved by a University of Manchester Ethical Review Board. Volunteers were enrolled into the study by responding to advertisements placed around the University campus.

Pure Tone Audiometry

Pure tone audiometry was performed using a GSI Arrow audiometer with TDH-39 headphones and MX41 AR cushions, following the British Society of Audiology Recommended Procedures (BSA, 2018). Participants were required to have audiometric thresholds of 20 dB HL or better in both ears at the octave frequencies between 250 Hz and 4000 Hz, with any asymmetry 10 dB or less at each frequency. Tympanometry was performed using a GSI Tympstar middle ear analyser, following recommended procedures (BSA, 2013). Normal tympanograms were also required to permit participation in the study (middle ear pressure +50 to -50 da Pa, middle ear compliance 0.3–1.6 cm3).

Acoustic reflex measurement

ARs were measured using a GSI Tympstar middle ear analyser. Ipsilateral reflex thresholds were measured from the right ear. The probe tone was a 226 Hz tone. The reflex eliciting stimuli were a 1000 Hz pure tone and a broadband noise (BBN), each of 1 second duration. The starting sound level was 70 dB HL for the 1000 Hz tone and 60 dB HL for the BBN. A reflex was defined as a reduction in compliance of at least 0.02 mmho. If no reflex was seen, the level of the elicitor was increased by 2 dB. Once a reflex was identified at a presentation level, an additional elicitor was presented at 2 dB above that presentation level to verify reflex growth (thus establishing the true presence of a reflex) before reducing the presentation level by 10 dB. The 2 dB step-wise increases were then repeated to establish a reliable response. The lowest sound level which produced a reliable response (reliable defined as producing a reflex on each of 3 consecutive presentations) was recorded as the ART.

Task conditions

The ART was estimated four times in each individual in a quasi-random ordering of task conditions. The four task conditions were as follows;

1 - Neutral (N): the ART was measured according to the standard procedure described above, without a specific task.

2 - Auditory Attention (AA): There were no additional stimuli presented, but participants were instructed to count and report the number of reflex-eliciting stimuli heard in the test ear. In this condition the attention of the listener was focussed on the auditory domain and directed towards the sounds which were integrally involved in measuring the AR.

3 - Auditory Distraction (AD): additional stimuli were presented via a BOSE Sound Link 2 loudspeaker located at eye level, 0 degrees azimuth and 1 metre from the participant. The stimuli were 2000 Hz tone pulses, with a random duration between 0.5 to 4 seconds, and random inter-pulse interval between 0.5 to 2 seconds. There were 8-12 tones presented in each block before a response was required. The sound level was calibrated using a Bruel and Kjaer sound level meter 2250 and was fixed at comfortable listening level of 74 dB SPL.

Stimuli were detected in the unoccluded left/contralateral ear, and participants reported the number of stimuli heard. In this condition, the listeners' attention was also focussed on the auditory domain, but the stimuli to which the listener had to attend to was not involved in eliciting or measuring the reflex. The purpose of this was to ascertain if attending to sounds which are not eliciting a reflex result in a change in the ART.

4 - Visual Distraction (VD): additional stimuli consisted of a black spot, easily visible, which appeared at pseudo-random positions on the computer screen for random durations (0.5 – 4 seconds) and with a randomly selected inter-presentation-interval from the interval 0.5 to 2 seconds. The stimulus was presented via a MacBook Air laptop, situated 1 meter from the participant at 0 degrees azimuth and at eye level. Participants were required to count the number of presentations of this spot. In this condition, the listeners' attention was explicitly directed away from the auditory domain.

For dual-task experimental conditions (2-4 above) participants were to be excluded if their reported count exceeded ±10 from the true value. No participants were excluded from the data analysis due to this criterion.

Results

The mean ARTs (and 95% confidence intervals) were obtained by averaging across the right ear of all participants, and are shown in Figure 1. The thresholds for the BBN elicitor were obtained with a sound level around 12 dB lower than those obtained using the 1000 Hz tonal elicitor, which is a well-established finding in the literature (Keefe at al., 2017; Causon et al., 2020).

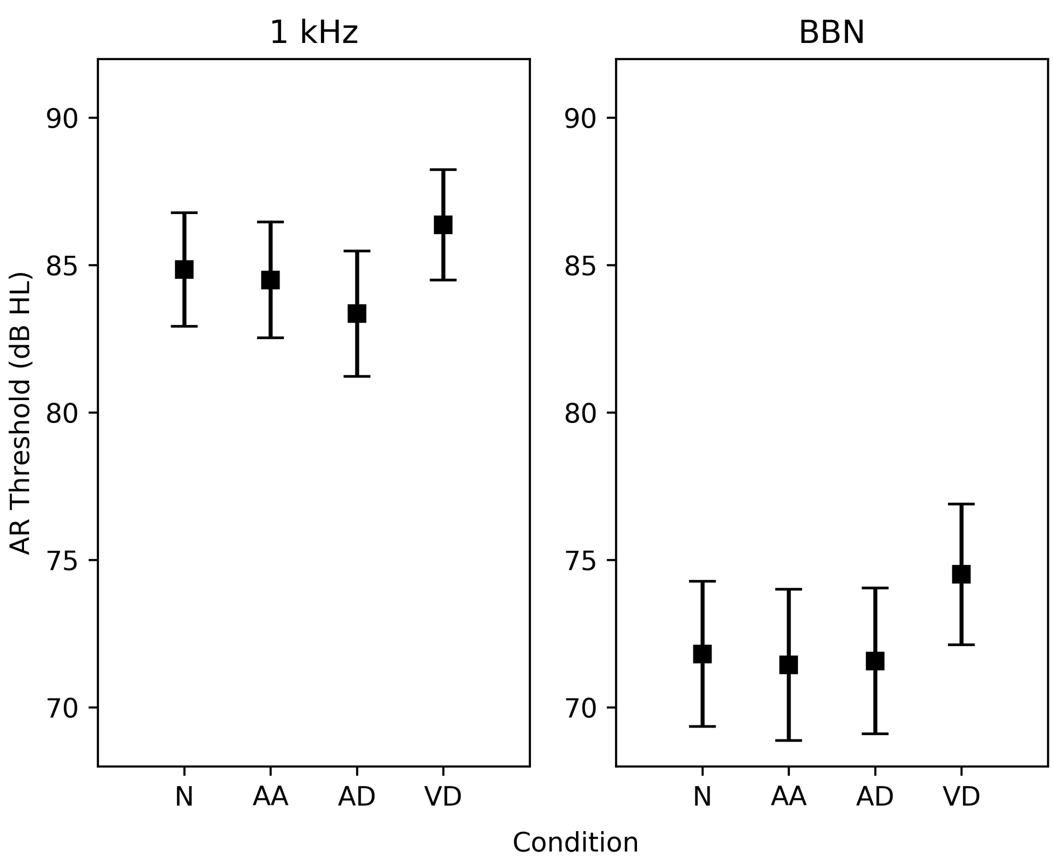

Figure 1: Mean ARTs (and 95% confidence intervals) are shown for each of the four conditions for both elicitors.

For the 1000 Hz tonal elicitor, the average threshold for the *VD* condition was 1.5 dB greater than the *N* condition and 1.9 dB and 3.0 dB greater than the *AA* and *AD* conditions, respectively. A one-way repeated measures ANOVA, corrected for a violation of sphericity, revealed a significant effect of condition; $F (3, 111) = 15.05$, $p < 0.001$). Post-hoc analyses indicated that the visual distractor condition resulted in significantly higher thresholds compared to all other conditions ($p \leq 0.002$).

For the BBN elicitor, the *VD* condition evoked thresholds which were on average 2.7 dB greater than those in the *N* condition and 3.1 dB and 2.9 dB greater than *AA* and *AD* thresholds, respectively. A one-way repeated measures ANOVA, corrected for a violation of sphericity, revealed a significant effect of condition; $F (3,111) = 12.98$, $p<0.001$. Post-hoc analyses indicated that the *VD* condition resulted in significantly elevated thresholds compared to all other conditions ($p<0.001$).

Discussion

The current experiment aimed to explore the effect of different attentional states on the acoustic reflex threshold. The hypothesis was that performing any task would result in an increase in ARTs. It was of interest to establish the size of these changes with modern acousto-electric bridges, and to observe if there was a difference between what we termed auditory attention and auditory distraction. Contrary to the expected effects, both auditory tasks resulted in no change in ARTs relative to the neutral condition. Only the visual task resulted in a statistically significant elevation of ART.

<u>*What is the mechanism for top-down modulation of these “automatic” responses?*</u>

It is our view that in order to understand the relevance of how attentional state and secondary tasks might impact hearing, both in the real world and the laboratory, we must understand the mechanism by which modulation of these responses occurs. Attentional state has been shown to affect a number of peripheral auditory responses, such as pure tone hearing thresholds (Heinrich et al., 2020), AR magnitude and threshold, evoked otoacoustic emissions (de Boer and Thornton 2007) and speech audiometry response times (Lee & Lee., 2022). Maison et al (2000) provide an outline of hypotheses which could explain the role of the top-down efferent system which projects from the medial oliviocochlear bundle to the outer hair cells of the cochlea. One of these hypotheses is that the system subserves attention and there are two main views; (i) the attentional mechanism is intermodal, and auditory peripheral responses are inhibited during a visual attention task (Hernandez-Peon, et al 1956), and (ii) an auditory attentional filter exists, in which auditory responses are inhibited by directed attention in the auditory domain (Froehlich et al 1990). Our data support the first of these hypotheses; however, it is difficult to reconcile this with the fact that other auditory responses, such as otoacoustic emissions and PTAs have been shown to also be affected by auditory attention tasks.

It is necessary to determine if the mechanism affecting all peripheral auditory responses is the same, and if so the extent to which it is domain specific. The best way to do this is to collect a number of baseline peripheral auditory responses in a single cohort of listeners and measure the extent to which these are inhibited by auditory and non-auditory attentional demands.

Is the effect size too small to be of interest or value?

The magnitude of change in ART was ~3 dB for the broadband elicitor, which is consistent with previous studies (Robinette and Snyder, 1982). As noted by Robinette and Snyder (1982), a change of this size is easy to dismiss as negligible and/or irrelevant; however, 14% their participants showed changes in ART greater than 10 dB. In our experiment, 4 (10%) participants showed changes of 8 dB or greater. It is still not clear whether there is any possible clinical, or real-world, consequence for a change in threshold of this size in a small percentage of people.

We certainly make no strong claims at the moment that this effect size is important. However, it must be acknowledged that many studies in this area: a) use well-controlled clinical settings for these measurements, and b) typically test healthy, normal hearing listeners. Heinrich et al. (2020) showed an effect of cognitive load on pure tone hearing thresholds in older listeners but not younger listeners. It is conceivable that the effect of a secondary task would be larger in listeners with elevated pure tone hearing thresholds and that the effect may be exacerbated in older listeners. It may also be the case that the effect is more pronounced in a real-world environment, which is less predictable. It is our view that further work involving a wider range of participant demographics and more ecologically valid experimental paradigms is needed before the effect can be dismissed as too small to be of clinical importance.

Potential implications for the clinic and the laboratory

It is desirable that clinical tests are accurate and reliable, in order to obtain the best evaluation of hearing health in a patient. There are some relatively straightforward extrapolations from these data which may have some clinical relevance. Cleaver (1974) showed that tightly closing the eyes increases the reflex magnitude. Indeed though we attribute the changes in ART on the visual distraction condition to attention, it could also be related to muscular movement of the eyes. This would be a good candidate for future study, investigating how visual attention tasks with and without significant eyes movements affect the AR. As noted earlier, the size of the effect may well be larger in listeners' with a hearing loss and with increased age. It may well be that the attention of a patient in the clinic needs controlling better. There may also be diagnostic and screening functions for the reflex beyond its current uses, for example in understanding how well central gain mechanisms are functioning (Brotherton et al., 2017), or as a compliment to speech-in-noise testing (de Andrade et al., 2011). But to unlock the utility of these approaches, the mechanistic processes underlying the reflex must be full characterized.

The AR is also a very popular research tool to study sub-clinical hearing changes in the field of cochlear synaptopathy. The reflex has been shown to be nearly absent in listeners with tinnitus, possibly due to lack of cochlear synapses (Wojtczak et al., 2017). It has also been shown in animal models that a reduced ART is a reliable indicator of an auditory system that has lost a significant number of cochlear synapses due to noise exposure (Valero et al., 2018). Recently a number of studies have used the acoustic reflex to further explore the possible role the AR has in elucidating cochlear synaptopathy in human listeners (Bharadwaj et al ., 2019; Mepani et al., 2019). However, the data presented here, in addition with historic literature on the affect secondary tasks have on the AR highlight the ways in which the nature of the AR may not translate analogously across different species.

Our primary aim in revisiting this topic was not specifically to quantify the magnitude of the threshold shift, but to establish which types of measures and tasks it makes sense to pursue further. It is clear from the experimental results presented here that the AR is affected by a visual attention task; consistent with an intermodal attentional hypothesis pertaining to the efferent projections from the medial oliviocochlear bundle to the cochlea. Our primary long-term goal is to understand what mechanisms underpin this change in ART and what clinical and real-world relevance it may have. This must be done across a range of different peripheral auditory responses in order to build up a coherent account of the mechanistic processes involved.

Conclusions

- We found mean ARTs to be elevated during a visual attention task by ~ 3 dB, but not by auditory attention/distraction tasks.
- The mechanism whereby visual attention affects automatic peripheral auditory responses remains unclear.
- Future work should cover a range of peripheral auditory responses in the same individuals and ascertain if the true effect size is larger in the real world than in the laboratory.
- Basic and translational research studies which use the AR as a quantitative response measure (for instance when studying deprivation, synaptopathy, central gain etc) may benefit from controlling these aspects of attentional influence.

Acknowledgments

GP, KJM, and AH are supported by the NIHR Manchester biomedical research centre.

<u>REFERENCES</u>

<u>REFERENCES</u>

Bell, DW. 1966. Effects of task performance upon the acoustic reflex. Unpublished doctoral dissertation. University of Southern California.

Bharadwaj HM, Mai AR, Simpson JM, Choi I, Heinz MG, Shinn-Cunningham BG. 2019. Non-Invasive Assays of Cochlear Synaptopathy - Candidates and Considerations. *Neuroscience*. 407:53-66. doi: 10.1016/j.neuroscience.2019.02.031.

Borg E, Counter SA, & Rosler G 1984. Theories of middle ear function In Silman S (ed.) The Acoustic Reflex: Basic Principles and Clinical Applications. Orlando FL: Academic Press, pp. 63–99.

Brask T. 1979. The noise protection effect of the stapedius reflex. Acta Otolaryngol Suppl. 360:116-7.

British Society of Audiology. Pure-tone air-conduction and bone-conduction threshold audiometry with and without masking. Recomm. Proced. Br. Soc. Audiol., Read. UK. 2018.

British Society of Audiology. Tympanometry. Recomm. Proced. Br. Soc. Audiol., Read. UK. 2013.

Brotherton H, Plack CJ, Schaette R, Munro KJ. 2017. Using acoustic reflex threshold, auditory brainstem response and loudness judgments to investigate changes in neural gain following acute unilateral deprivation in normal hearing adults. Hear Res. 345:88-95.

Causon A, Munro KJ, Plack CJ, Prendergast G. The Role of the Clinically Obtained Acoustic Reflex as a Research Tool for Subclinical Hearing Pathologies. *Trends in Hearing*. 2020;24. doi:10.1177/2331216520972860.

Cleaver VCG. 1974. The effects of mental set on the acoustic reflex. M.Sc. Dissertation, University of Southampton, England.

de Andrade KC, Camboim ED, Soares Ido A, Peixoto MV, Neto SC, Menezes Pde L. 2011. The importance of acoustic reflex for communication. *Am J Otolaryngol.* 32, 221-7.

de Boer J, Thornton AR. Effect of subject task on contralateral suppression of click evoked otoacoustic emissions. Hear Res. 2007 Nov;233(1-2):117-23. doi: 10.1016/j.heares.2007.08.002.

Durrant JD, Shallop JK. 1969. Effects of differing states of attention on acoustic reflex activity and temporary threshold shift. J Acoust Soc Am. 46:907-13.

Froehlich P, Collet L, Chanal JM, Morgon A. Variability of the influence of a visual task on the active micromechanical properties of the cochlea. *Brain Res.* 508:286-8.

Gelfand SA 2009. The acoustic reflex In: Katz J, Medwetsky L, Burkard R & Hood L (eds.) Handbook of Clinical Audiology. Philadelphia, PA: Wolters Kluwer, pp. 189–221.

Gruters KG, Murphy DLK, Jenson CD, Smith DW, Shera CA, Groh JM. The eardrums move when the eyes move: A multisensory effect on the mechanics of hearing. Proc Natl Acad Sci U S A. 2018 Feb 6;115(6):E1309-E1318.

Heinrich, A., Ferguson, M.A., Mattys, S.L. (2020) Effects of cognitive load on pure-tone audiometry thresholds in younger and older adults. *Ear and Hearing, 41(4)*, 907-917.

Hernandez-peon R, Scherrer H, Jouvet M. 1956. Modification of electric activity in cochlear nucleus during attention in unanesthetized cats. *Science* 24;123, :331-2.

Keefe DH, Feeney MP, Hunter LL, Fitzpatrick DF. 2017. Aural Acoustic Stapedius-Muscle Reflex Threshold Procedures to Test Human Infants and Adults. *Journal of the Association for Research in Otolaryngology : JARO*, *18*(1), 65–88.

Klockhoff I. 1961. Middle ear muscle reflexes in man. A clinical and experimental study with special reference to diagnostic problems in hearing impairment. *Acta Otolaryngol Suppl.* 164:1-92.

Lee SJ, Lee S. 2022. Clinical utility of response time in speech audiometr*y in elderly with mild cognitive impairment, International Journal of Audiology.* Available online.

Maison SF, Liberman MC. 2000. Predicting Vulnerability to Acoustic Injury with a Noninvasive Assay of Olivocochlear Reflex Strength. *Journal of Neuroscience*. 20 (12) 4701-4707.

Mepani AM, Kirk SA, Hancock KE, Bennett K, de Gruttola V, Liberman MC, Maison SF. 2019. Middle ear muscle reflex and word recognition in “normal-hearing” adults: Evidence for cochlear synaptopathy? *Ear and Hearing*, 41, 25–38.

Nixon GK, Sarant JZ, Tomlin D. 2019. Peripheral and central hearing impairment and their relationship with cognition: a review. *International Journal of Audiology*, 58:9, 541-552.

Prasher D, Cohen M. 1993. Effectiveness of Acoustic Reflex Threshold Criteria in the Diagnosis of Retrocochlear Pathology, *Scandinavian Audiology*, 22:1, 11-18.

Robinette MS, Snyder KS. 1982. Effect of eye closure, mental concentration, and nonauditory sensory stimulation on the threshold and magnitude of the acoustic reflex. Ear Hear. 3:220-6.

Tasko SM, Deiters KK, Flamme GA, Smith MV, Murphy WJ, Jones HG, Greene NT, Ahroon WA. Effects of unilateral eye closure on middle ear muscle contractions. Hear Res. 2022 424:108594.

Ugarteburu M, Withnell RH, Cardoso L, Carriero A, Richter CP. Mammalian middle ear mechanics: A review. Front Bioeng Biotechnol. 2022 Oct 10;10:983510. doi: 10.3389/fbioe.2022.983510.

Valero MD, Hancock KE, Maison SF, Liberman MC. 2018. Effects of cochlear synaptopathy on middle-ear muscle reflexes in unanesthetized mice. Hear Res. 363:109-118.

Wojtczak M, Beim JA, Oxenham AJ. 2017. Weak Middle-Ear-Muscle Reflex in Humans with Noise-Induced Tinnitus and Normal Hearing May Reflect Cochlear Synaptopathy. *eNeuro*. 27;4:ENEURO.0363-17.