

IPSILATERAL MEASUREMENT OF THE ACOUSTIC REFLEX

USING WIDEBAND POWER REFLECTANCE

By

SARAH ANNA MACKENZIE

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Approved by:

Dr. David Velenovsky
Department of Speech, Language, and Hearing Sciences

ABSTRACT

The contraction of the stapedius muscle is known as the acoustic reflex (AR), which stiffens the ossicular chain/tympanic membrane. Conventional immittance systems only evaluate changes in admittance for the 226 Hz probe tone with AR activation. Conversely, wideband power reflectance (WPR) provides information regarding energy reflected from the tympanic membrane across a broad frequency range, typically 200 to 6000 Hz. Thus, WPR has the potential to reveal more information regarding the effects of AR activation on sound passing through the middle ear. The purpose of this study was to determine if acoustic reflexes can be measured ipsilaterally (IPSI) by WPR using a novel protocol. Pure tone or broadband noise stimuli typically used for IPSI reflex recording could not be employed when measuring the reflex via WPR. This is because the levels needed to activate the AR for pure tone stimuli are much higher (85-100 dB SPL) than the chirp stimulus (62 dB SPL) and would thus contaminate the reflectance measure. Therefore, we used the WPR chirp stimulus as both the probe stimulus and reflex elicitor for our IPSI reflex measures.

Ipsilateral AR thresholds measured using the wideband chirp stimulus were comparable to conventionally measured IPSI ARs. Our study demonstrates the potential of wideband power reflectance as a measure of the ipsilateral acoustic reflex using the chirp stimulus as both the probe and the elicitor.

INTRODUCTION

The contraction of the stapedius muscle stiffens the ossicular chain and the tympanic membrane. This is known as the acoustic reflex (Borg, 1968). The ossicular chain comprises three small bones, the malleus, incus and stapes. These three articulated bones connect the tympanic membrane to the cochlea and are responsible for transferring acoustic energy from the tympanic membrane to the inner ear. The stapedius muscle tendon attaches to the head of the stapes. As the tympanic membrane stiffens as a result of contraction of the stapedius muscle, acoustic energy is more readily reflected or admitted depending upon frequency. As stiffness increases, low frequency energy is more readily reflected, and high frequency energy is more readily admitted. Conventionally, clinicians use immittance testing to measure the AR. The acoustic reflex offers clinical audiologists information about the mechanical (middle ear) and neural (lower auditory brainstem and facial nerve) functionality of the auditory pathway, both ipsilaterally and contralaterally. Silman and Gelfand (1981) investigated the relationship between AR thresholds and magnitude of hearing loss due to cochlear pathologies, and found that thresholds can be elevated with hearing loss. These investigators suggested that AR thresholds may be a useful diagnostic tool for retrocochlear pathologies, that is, pathologies of the VIII cranial nerve. Recently, a new test of middle ear integrity, wideband power reflectance, has been introduced clinically and may be a more reliable and sensitive measure of the AR than conventional immittance testing. Feeney, Keefe, and Sanford (2004) successfully demonstrated that wideband power reflectance has the potential to be a powerful tool in finding AR thresholds that were previously missed in traditional immittance testing. Rosowski, Stenfelt, and Lilly (2013) demonstrated the advantage of WPR over traditional immittance measures in that it is not as sensitive to variations in ear canal length resulting from probe insertion. Additionally, immittance systems only evaluate changes in admittance for the 226 Hz probe tone. While this is a good tool in assessing middle ear function (Nakajima, Rosowski, & Shahnaz, 2013), wideband power reflectance measurements of the AR reveal the effect of the reflex on the admittance of a significantly broader frequency range (typically 200-6000 Hz). This advantage of WPR for AR

measures can provide more information on the filtering effects of AR activation across frequency, possibly offering information on how the AR filters sounds in the speech range in noisy situations.

Several investigators have explored using WPR to measure the AR. The majority of these studies involved measurements of the contralateral AR, which have fewer limitations as the reflex elicitor is in the ear opposite the probe. The technique developed by Feeney and Keefe (2004) demonstrated how to use spectral separation of elicitor to avoid contamination of the probe for ipsilateral measurements of the AR. By using a 4 kHz elicitor these investigators avoided the

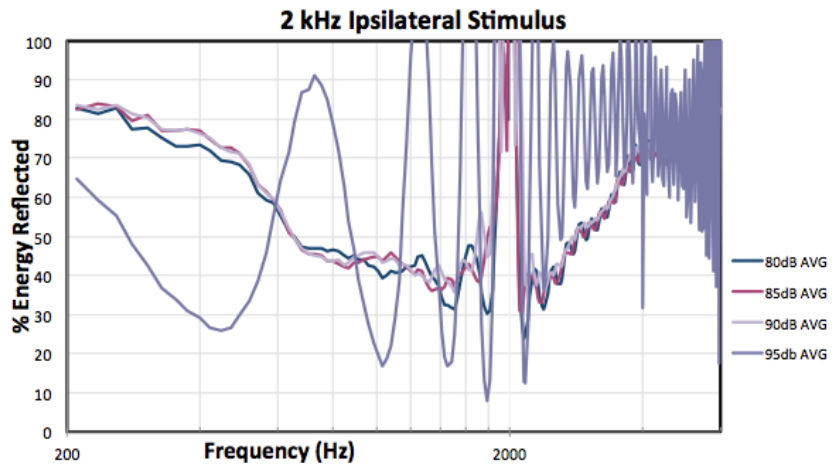


Figure 1: Example of contamination by a 2 kHz stimulus encountered when measuring ipsilateral AR thresholds.

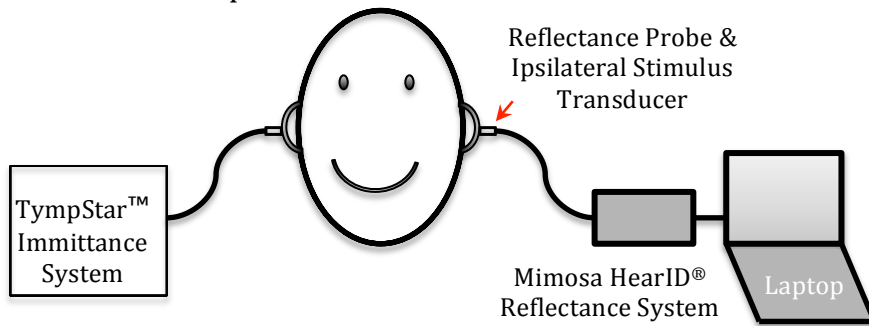
masking effects present with the elevated levels of a low frequency pure tone stimuli. However, AR thresholds elicited by a 4kHz probe tone are variable and often do not have significant clinical value (Jerger, Jerger, & Mauldin, 1972). Pure tone or broadband noise stimuli typically used for IPSI reflex recording could not be employed when measuring the reflex via WPR. This is because the levels needed to activate the AR using pure tone stimuli are much higher (@ 85-100 dB SPL) than the chirp stimulus (62 dB SPL) and would thus mask any change in reflectance that would be present from reflex activation (See Figure 1). Therefore, I used the WPR chirp stimulus as both the probe stimulus and reflex elicitor for our IPSI reflex measures.

In order to establish the viability of using the WPR chirp stimulus as the probe stimulus and reflex elicitor, three cross checks were employed. First, ipsilaterally measured WPR curves were compared to contralaterally measured WPR curves in the same subject. The general shape and effect of increased stimulus level across frequency were found to be comparable (See Figure 4a and b). Second, in order to determine if the increased energy present was due to increased probe energy or effects of AR activation, ipsilateral WPR data were collected from a deaf participant (who would not have acoustic reflexes). These data were compared to those from a normal hearing participant. The comparison results demonstrated that no significant change in % energy reflected occurred due to increased stimuli level (See Figures 4b and c). Third, we confirmed the presence of an ipsilateral reflex by simultaneously measuring the presence of a contralateral reflex. In a typical individual, the acoustic reflex will occur bilaterally when one or both ears are presented with an eliciting stimulus. This simultaneous measurement of contralateral AR was performed using the reflex decay function of a GSI TympanStar™ as the GSI and Mimosa systems could not be synchronized using a mutual trigger.

METHODS

We tested 40 participants, male and female between the ages of 18-60, and accepted 34 left ear and 36 right ear measurements. Participants passed a screening battery comprising otoscopy, pure tone audiometry, tympanometry, and ipsilateral acoustic reflexes. They had clear ear canals with no visual occlusion and clear tympanic membranes with no perforations and minimal

vascularization. Participants passed a hearing screening at a level of 20 dB HL bilaterally at 500, 1000, 2000, 4000, and 8000 Hz. Tympanometric middle ear peak pressure was between ± 25 mmH₂O and ipsilateral acoustic reflex thresholds were determined for BBN, 500, 1000, 2000,



4000 Hz. Participants were accepted regardless of acoustic reflex level.

We completed immittance testing using a GSI TympStar™ Middle Ear Analyzer while the participant was seated in a sound treated booth. WPR measurements of IPSI AR thresholds were completed bilaterally with a Mimosa Acoustics HearID® 5.1 system (See Figure 2). *in situ* probe calibration was completed using

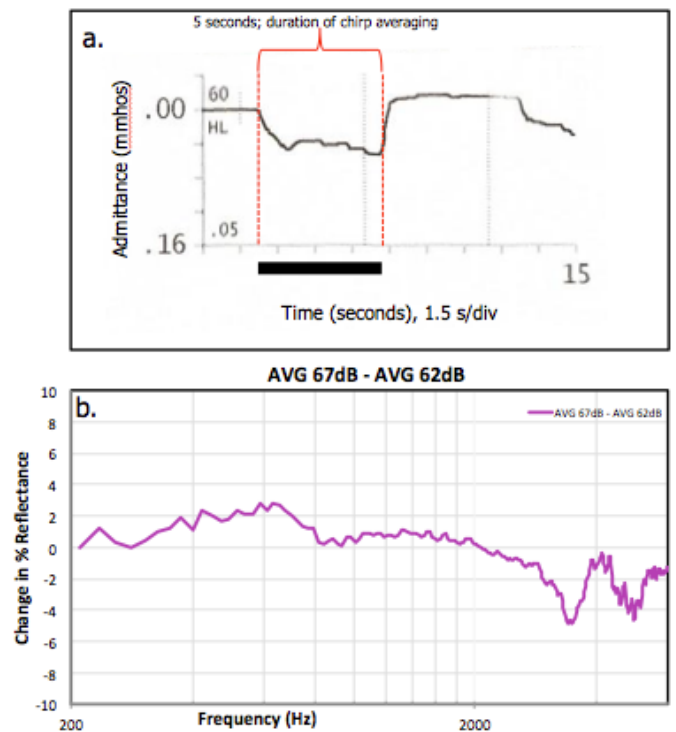
Figure 2: Diagram of the set up of WPR measured ipsilaterally with simultaneous contralateral reflex measurement.

a 1000 Hz tone. A signal-to-noise ratio (SNR) below 40 dB SPL resulted in removal and re-insertion of the ER10c probe. The WPR chirp stimulus was used as both the probe and reflex elicitor for our IPSI reflex measures.

The chirp stimulus was presented at a baseline level (62 dB SPL) four times to determine response stability. The chirp was then presented at four condition levels: 67, 72, 77, and 80 dB SPL (maximum output of HearID® 5.1 system). For each dB SPL condition, the chirp was presented four times at 62 dB SPL (non-elicitor level) and at 67, 72, 77, or 80 dB SPL (elicitor levels) alternatingly for a total of eight measurements per condition.

Simultaneous measurement of contralateral AR thresholds using a GSI TympStar™ was performed once at each condition level (See Figures 3a & b). A measurement was accepted if the reflectance curve was consistent in pattern and if there was low variability in the noise floor. Results from our contralateral acoustic reflex measures using WPR revealed an expected effect across frequency caused by increased stiffness from activation of the reflex. This pattern served as a reference to determine the presence of an IPSI AR at different elicitor levels.

Data were analyzed using % power reflectance measures. To determine changes in reflectance via an elicitor stimulus, the average of four transmittance runs for each frequency at baseline



Figures 3a & b: In some cases contralateral reflexes were measured concurrently with ipsilateral measures using WPR. Figure a. shows a reflex elicited by the ipsilateral WPR chirp stimulus measured using the TympStar probe. Figure b. shows the ipsilateral acoustic reflex elicited and measured using WPR.

were subtracted from the average of four transmittance runs at each frequency for a given elicitor level.

Data were submitted to a repeated measures ANOVA to determine whether a change in reflectance level at a given frequency was significantly different from the baseline measure, thus indicating the presence of an acoustic reflex.

All methods were approved by the University of Arizona Institutional Review Board, Project # 13-0687.

RESULTS

In figures 4a & b reflectance curves are shown for contralateral and ipsilateral WPR measurement for the same participant, respectively. These figures demonstrate the consistency in reflectance pattern across frequency between the two protocols for WPR reflex measurement. Contralateral measurements were recorded using a BBN stimuli and the MEPA HearID® chirp probe stimulus. The consistency in effect for change in % reflectance between the two measurements demonstrate the expected pattern of growth when an acoustic reflex is activated. Figure 4c represents change in % reflectance for ipsilateral WPR of a deaf participant. The effect of increased chirp stimuli level is insignificant for this participant across frequency. Thus, the effects

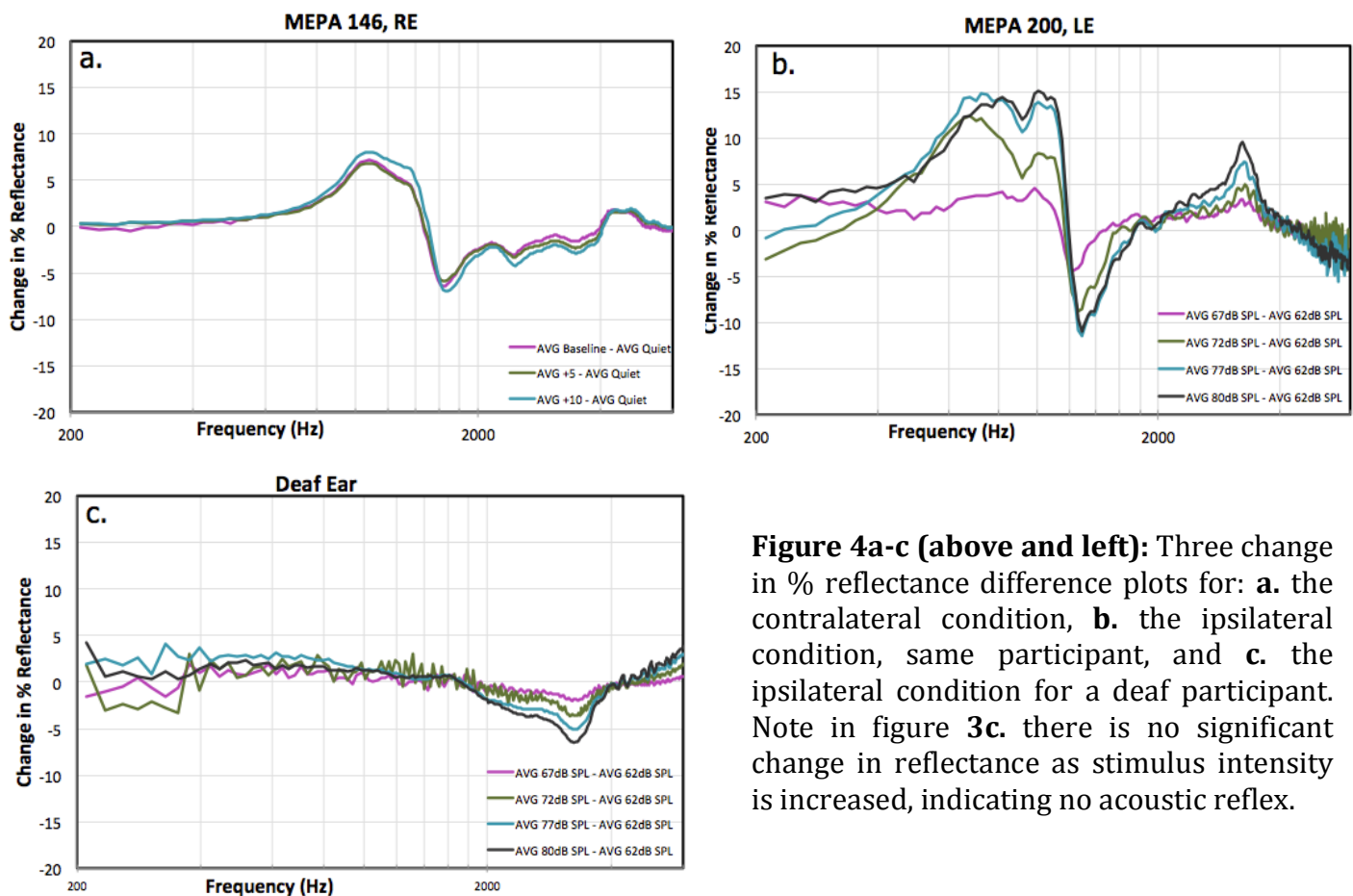


Figure 4a-c (above and left): Three change in % reflectance difference plots for: **a.** the contralateral condition, **b.** the ipsilateral condition, same participant, and **c.** the ipsilateral condition for a deaf participant. Note in figure 3c. there is no significant change in reflectance as stimulus intensity is increased, indicating no acoustic reflex.

present in ipsilateral WPR measurements are not due to increase of energy from elevated stimuli levels alone.

Individual reflectance measures submitted to a repeated measures ANOVA revealed significant changes in reflectance level at a given frequency from the baseline measure. Changes in reflectance level as compared to condition, threshold group, and band were significant ($p < 0.000$).

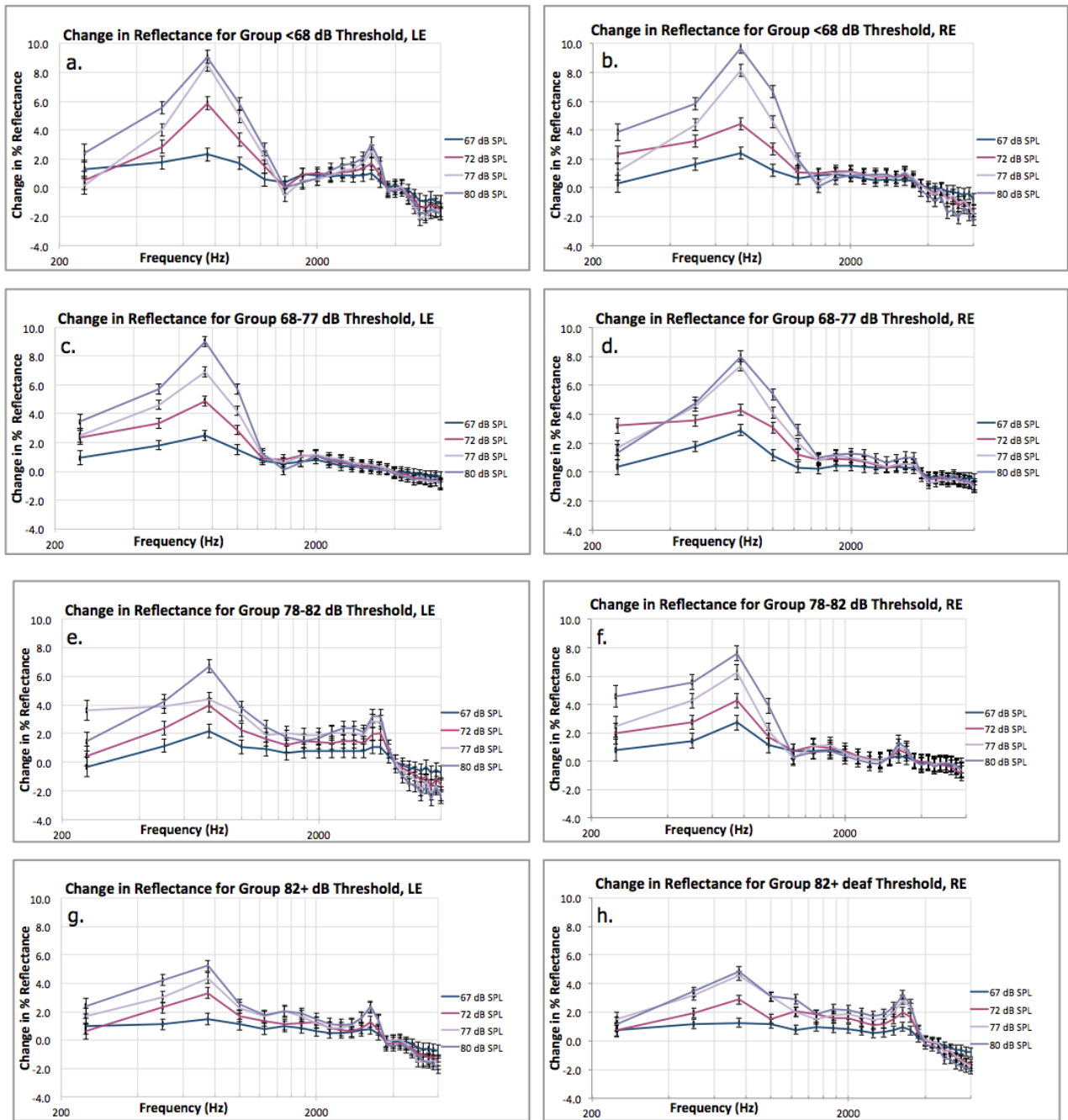


Figure 5a-h (above): These figures show means of ipsilateral WPR AR measurements grouped by conventional BBN ipsilateral AR threshold (<68, 68-77, 78-82, 82+ dB SPL). **a, c, e, g.** represent the left ear, and **b, d, f, h.** represent the right ear. Note that most of the change occurs between 500 and 1250 Hz for all groups. Note also that for the higher threshold groups (78-82 & 82+ dB SPL) that change is seen centered at 3250 Hz. Error bars = standard error of the mean.

These results suggest that when participants were grouped by conventional BBN ipsilateral AR thresholds, the effects seen in each stimulus level condition separated by 250 Hz bands were significant when compared to the baseline condition. Figures 5a-h show averaged change in % reflectance for participants grouped by conventionally measured BBN AR thresholds and separated by ear.

Source	Numerator df	Denominator df	F	Sig.
Condition#	3	68610	319.413	0.000
band250Hz	23	68610	1779.697	0.000
Ear * Condition# * ThresholdGroup band250Hz	207	68610	2.213	0.000
Condition# * ThresholdGroup	9	68610.000	2.355	0.012
ThresholdGroup * band250Hz	69	68610.000	47.516	0.000
Condition# * ThresholdGroup * band250Hz	207	68610.000	4.290	0.000

Table 1: Mixed model ANOVA showing significance effects of frequency band, condition, and threshold group.

DISCUSSION

Ipsilateral WPR change in % reflectance ($\Delta\%$ Ref) measurements were collected from 34 L and 36 R ears to determine the presence of an acoustic reflex. Effects across frequency and response growth were found to be similar to contralateral WPR AR measurements made in our lab. The measurements of the deaf ear demonstrated that increased stimulus level did not result in significant $\Delta\%$ Ref across frequency. The ipsilateral WPR AR measurements were confirmed by concurrently measuring the contralateral AR using the reflex decay function of the GSI TympStar™. Due to the limited chirp stimulus output (HearID® max. output level is 80 dB SPL), the stimulus level could not be normalized to AR threshold. Instead, the reflex elicitor stimulus was presented at 62, 67, 72, 77, and 80 dB SPL and the effect was observed. Therefore, in order to best visualize the effect of increased level on AR, data were grouped by BBN AR threshold determined using the GSI TympStar™. Table 1 above demonstrates that these changes in effect by changes in level are significant across frequency band. Figures 5a-h, show the effect by band. As stimulus level increases, $\Delta\%$ Ref increases. Using WPR for AR measures allows us to see the effect of the reflex across frequency, which was greatest between 500-1250 Hz. Interestingly this frequency range does not include 226 Hz, the standard probe frequency in conventional immittance systems. We also noted additional effects in the high frequencies (centered at 3250 Hz) for 78-82 and 82+ dB SPL BBN AR threshold groups. Ochi, Ohashi, and Kinoshita (2002) suggest that the acoustic stapedius reflex has an inhibitory effect on the tensor tympani reflex. However, the effect of the

contraction of the tensor tympani may be observed when the acoustic reflex threshold is elevated or absent ipsilaterally. I suggest that the tensor tympani muscle may be responsible for the $\Delta\%$ Ref seen centered at 3250 Hz.

In summary, it is suggested that using the WPR chirp as both the probe stimulus and reflex elicitor is a viable protocol for measuring the ipsilateral AR using WPR. However, increased output of our present system is needed to fully explore the effects of the IPSI reflex. Conventional acoustic reflex measurement has been proposed as a tool for the diagnosis of cochlear and retrocochlear disorders (Jerger, Harford, Clemis, & Alford, 1974; Silman & Gelfand, 1981; Hirsch, A., 1983; Clemis, J.D., 1984). However, more recently it has been suggested that WPR measurement of the AR may provide important diagnostic information when assessing for cochlear neuropathy (Valero, Hancock, & Liberman, 2015). Cochlear neuropathy, or hidden hearing loss, is neural hearing loss due to damage of auditory nerve fibers without damage or loss of inner hair cells. This disorder is difficult to diagnose because hearing thresholds from conventional audiometric evaluations reveal typical threshold sensitivity. Valero et. Al.,(2015) suggested that because low spontaneous rate auditory nerve fibers may be important in acoustic reflex occurrence, damage to these fibers would result in hearing loss that is undetectable by audiometry alone. They suggest that the frequency information provided by WPR measures of the AR would aid in this diagnosis. Thus, this new protocol may allow for further development of retrocochlear and cochlear diagnostic tools.

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