Acoustic Reflex Measurement

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Middle ear muscle reflex (MEMR) measurements have been a part of the standard clinical immittance test battery for decades as a cross-check with the behavioral audiogram and as a way to separate cochlear from retrocochlear pathologies. MEMR responses are measured in the ear canal by using a probe stimulus (e.g., single frequency or broadband noise) to monitor admittance changes elicited by a reflex-activating stimulus. In the clinical MEMR procedures, one test yields changes in a single measurement (i.e., admittance) at a single pure tone (e.g., 226 or 1000 Hz). In contrast, for the wideband acoustic immittance (WAI) procedure, one test yields information about multiple measurements (e.g., admittance, power reflectance, absorbance) across a wide frequency range (e.g., 250 to 8000 Hz analysis bandwidth of the probe). One benefit of the WAI method is that the MEMR can be identified in a single test regardless of the frequency at which the maximum shift in the immittance measurement occurs; this is beneficial because maximal shifts in immittance vary as a function of age and other factors. Another benefit is that the wideband response analysis yields lower MEMR thresholds than with the clinical procedures. Lower MEMR thresholds would allow for MEMR decay tests in ears in which the activator levels could not be safely presented. Finally, the WAI procedures can be automated with objective identification of the MEMR, which would allow for use in newborn and other screening programs in which the tests are completed by nonaudiological personnel.

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MEMR MEASUREMENTS OBTAINED WITH A PURE-TONE PROBE

A standard clinical immittance test battery includes measurements of the acoustic reflex, or more specifically, the middle ear muscle reflex (MEMR). The MEMR is the contraction of the stapedius muscle in response to high-level acoustic stimulation. Clinical MEMR measurements are made according to the American National Standards Institute standard for immittance instruments (S3.39–2012) by use of a 226-Hz probe tone in conjunction with a reflex-activating stimulus presented to the ipsilateral or contralateral ear. The MEMR is a bilateral response, which means that presenting the activator to one ear will elicit the response in both ears. In traditional clinical measurements, the reflex activator stimulus is a pure tone (500, 1000, 2000, or 4000 Hz) or a broadband noise, and the MEMR is measured at tympanometric peak pressure (TPP) as measured on the tympanogram. If the admittance of the test ear decreases by a criterion amount in the presence of the activator, for example, 0.02 to 0.03 mmho, the reflex is considered to be present. The lowest level at which an activator is presented and reliably elicits at least the criterion change in admittance is considered the MEMR threshold. The MEMR is typically present in ears with pure-tone behavioral thresholds of ≤60 dB HL at the activator frequencies (Gelfand 2009).

Limitations of the Pure-Tone Probe MEMR Test

MEMR threshold measurements obtained using pure-tone probes have an existing evidence base and have been an integral part of the audiological diagnostic test battery for decades. However, there are a few technical limitations of traditional MEMR measurements.

First, a 226-Hz probe tone is typically used for MEMR measurements in older children and adults. MEMR threshold varies with probe frequency (McMillan et al., 1985), and due to developmental issues (see Kei et al., this issue, pp. 17S–26S), higher probe-tone frequencies (660, 800, and 1000 Hz) can be used to improve MEMR detection in infants (Weatherby & Bennett 1980; Kankkunen & Liden 1984; Sprague et al. 1985; Hirsch et al. 1992). However, normative data are limited (e.g., Mazlan et al. 2007, 2009), the option is not available on all equipment, and when the option is available, it takes extra time to obtain MEMR measurements with multiple probe-tone frequencies.

Second, although an objective criterion change in admittance is used to determine presence of an MEMR (i.e., 0.02 mmho), the final judgment of whether an MEMR is present relies on a visual, subjective determination by the examiner. The examiner must confirm that the change in admittance is in the correct direction (a decrease, not an increase), time-locked to the stimulus rather than noise from patient movement, and valid if the baseline is unstable. This is not usually a problem for experienced audiologists, but it limits the utility of the test in applications such as newborn hearing screenings that may be performed by nonaudiological personnel. MEMR screening tests and automatic MEMR threshold tests are available in some commercially available equipment. However, they may be limited in activator frequency, and they may be more susceptible to artifact from patient movement because only one presentation of the activator is presented at a given level.

Finally, MEMR decay measurements conducted to test eighth nerve integrity as a screening for retrocochlear pathology are typically conducted with the reflex-activating tone presented at 10 dB above MEMR threshold. Thus, reflex decay cannot be conducted when reflex thresholds are so high that the reflex decay stimulus would exceed the stimulus limits of the system, or if the activator would be presented at such a high level that it could potentially cause hearing loss. There is evidence of temporary and permanent behavioral threshold shifts (TTS and PTS, respectively) in cases in which the activator was presented at a level above 105 dB HL. Hunter et al. (1999) reported TTS at frequencies above 1000 Hz and a PTS at 1000 Hz after an acoustic reflex decay test using a1000 Hz tone at level of 120 dB HL. Arriaga and Luxford (1993) reported a PTS at 2000 Hz after presentation of a 2000 Hz activator at 120 dB HL in one

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ear of an older patient with hearing loss. Miller et al. (1984) reported PTS and a temporary decrease in speech discrimination in an older patient. Thus, an MEMR test that would result in lower MEMR thresholds would be useful in avoiding high presentation levels for the MEMR decay test.

MEMR MEASUREMENTS OBTAINED WITH A WIDEBAND PROBE

Immittance measurements that are obtained with a wideband probe such as a click or chirp are referred to in this volume as wideband acoustic immittance (WAI). Measuring the MEMR with a wideband probe rather than a single-probe frequency allows the MEMR to be detected simultaneously across several octaves, thus providing a sensitive test of the reflex for adults and infants. A summary of WAI MEMR studies is shown in Table 1. In most studies, the clinical MEMR measurements were made with the GSI-33 or Tympstar devices (Grason-Stadler Inc., Eden Prairie, MN) and a 226 Hz probe. The exceptions were studies by Keefe et al. (2010) and Feeney and Sanford (2005) in which a 1000 Hz probe was used when testing infants. The MEMR criterion was 0.03 mmho in the clinical measurements with the exception of Schairer et al. (2007) in which the criterion was 0.02 mmho. The ER-10C probe (Etymotic Research Inc., Elk Grove Village, IL) was used in the WAI measurements in all studies except the study by Keefe et al. in which a wideband tympanometer (Interacoustics, Assens, Denmark) was used. Most WAI MEMR measurements were made at ambient pressure, with the exception of Keefe et al., in which the MEMR measurements in adults were obtained at ambient pressure and at TPP. Adults in all studies and the children in the Schairer et al. study had normal hearing. Infants in the Feeney and Sanford study passed an otoacoustic emissions (OAEs) screen.

Feeney and Keefe (1999) elicited contralateral (probe right, activator left) MEMR-induced changes in admittance, power reflectance, and absorbed power of a 40-msec chirp probe using a system developed by Keefe et al. (1992). An ER-10C was used to present the probe and record responses in the ear canal. An audiometer was used to present the 1000 and 2000 Hz activators. During data collection, the probe was turned on and off manually on a computer by one experimenter, and the activators were presented manually by a second experimenter. Identification of the MEMR was made by visual inspection of the comparison between an average of WAI responses to eight chirps before the onset of the activator and the WAI responses when the activator was presented. In the presence of the activator, power reflectance increased at low frequencies and often decreased above some transition frequency around 1000 Hz. Admittance and absorbed power decreased at low frequencies and increased above a transition frequency. MEMRs identified in WAI measurements were present at least 8 dB lower than the MEMR thresholds obtained with the pure-tone probe, with the exception of one subject in the 2000 Hz activator condition. In this study, a fixed set of activator levels was used (±8 dB in 2-dB steps relative to clinical MEMR threshold), and WAI MEMR thresholds may have been below the lowest activator level that was presented.

Feeney and Keefe (2001) used the same procedures as they did in 1999, with the exceptions of a larger range of activator levels in the WAI test, white noise rather than pure-tone activators, and two objective statistical methods to identify the presence of the WAI MEMR. The range of activator levels in the WAI MEMR measurements was −32 to +8 dB in 2-dB steps relative to the clinical MEMR threshold. Magnitude and correlation tests were use to detect an MEMR-induced shift in the wideband probe. The MEMR thresholds obtained with the wideband probe were up to 24 dB lower than thresholds obtained with a pure-tone probe depending on the method used to identify the WAI MEMR. In a third study with a larger set of subjects, Feeney et al. (2003) used similar methods to those used by Feeney and Keefe (2001). The range of activator levels in the WAI MEMR measurements in the 2003 study was −24 to +4 dB in 4 dB steps relative to the clinical MEMR threshold. Feeney et al. observed that contralateral MEMR thresholds for 1000 and 2000 Hz activators identified in WAI measurements of admittance and power reflectance were, on average, 13 dB lower than clinical MEMR thresholds. Finally, Feeney et al. (2004) measured WAI MEMR thresholds using a filtered-click probe, a 4000 Hz activator presented through an ER-10C rather than an audiometer, an adaptive MEMR threshold search procedure, and a 16-click baseline. The activator levels were presented in 2 dB steps starting from clinical MEMR threshold or 92 dB HL. The authors observed that average contralateral WAI MEMR thresholds were 3 dB lower than the clinical MEMR thresholds. Ipsilateral WAI MEMR thresholds were obtained but not compared with pure-tone MEMR thresholds.

Schairer et al. (2007) used an automated system to test adults and children using a click probe and ipsilateral activators of 1000 and 2000 Hz and a broadband noise. Activator levels were presented to adults in a fixed range from 16 dB below the maximum output in 4 dB steps up to the maximum output (5 levels total). Step sizes in children were 5 dB and the range included two additional lower levels. In their method, a click probe was present throughout the measurement window, with a baseline of responses to only the clicks, followed by responses to the clicks plus the activator, and finally responses to clicks after the activator was turned off. (A modified version of the stimulus presentation sequence used in Keefe et al. (2010) is shown in Fig. 1.) The probe/activator series was presented three times and responses were averaged across repetitions. The click that was presented directly after activator offset was excluded from analysis to avoid contamination by OAEs that were elicited by the higher activator levels. The difference in wideband admittance and power reflectance between postactivator versus baseline click responses was calculated as a function of frequency in third-octave bands from 320 to 2000 Hz. A repeated-measures analysis of variance was completed to determine whether the shifts in any of the third-octave bands was significantly different from zero. The lowest activator level that produced a significant MEMR shift in any third-octave band was defined as threshold. This analysis was completed at each activator level and frequency, and in each ear. An additional rule was that the highest activator level did not produce a significant shift in a coupler. Schairer et al. reported that WAI MEMR thresholds in adults were lower than 226 Hz probe MEMR thresholds by 2.2 to 4.0 dB. No differences between WAI and clinical MEMR thresholds were observed in the child group, however, the authors noted that the results should be interpreted with caution due to the small sample size and large standard error for tonal activators.

TABLE 1. Summary of WAI MEMR studies

Study	Feeney & Keefe 1999	Feeney & Keefe 2001	Feeney et al. 2003	Feeney et al. 2004	Feeney & Sanford 2005	Schairer et al. 2007	Keefe et al. 2010
Subjects	3 women, 22–25 yrs	Exp 1: same as Feeney & Keefe 1999 Exp 2: 4 adults	34 (17 women), 18–26 yrs	27 (17 women), 18–31 yrs	8 infants (5 girls), 5.6 to 6.3 weeks 3 adults (1 woman), 18.2–18.6 yrs	Group 1: 21 (15 women), 18–36 yrs; 40 ears; Group 2: 14 (8 girls), 2.5–6.8 yrs, 21 ears	Adults: 40, 80 ears Infants: 230 (100 girls), 455 ears; 1–2 days old
Activator	1000 and 2000 Hz	White noise	1000 and 2000 Hz	4000 Hz	Broadband noise	1000 and 2000 Hz, broadband noise	Ipsi: 500, 1000, 2000 and 4000 Hz, and broadband noise. Contra: 500 and 1000 Hz
Activator ear	Contralateral	Contralateral	Contralateral	Clinical: contralateral WAI: both	Contralateral	Ipsilateral	Clinical: ipsi and contra in adults WAI: ipsi in adults and infants; contra in adults
Identification of WAI MEMR	Visual inspection	Consecutive-correlation method and magnitude method	Consecutive-correlation method and magnitude method	Consecutive-correlation method and magnitude method	Cross-correlation	Repeated-measures analysis of variance	Maximum likelihood in two frequencies bands
WAI MEMR vs. Clinical MEMR	WAI MEMR present at least 8 dB below clinical MEMR threshold	WAI MEMR thresholds up to 24 dB lower than clinical MEMR thresholds (average of 14 dB lower Exp 1, 18 dB lower Exp 2)	Average WAI MEMR thresholds 12–13.7 dB lower than clinical MEMR thresholds	Average WAI MEMR thresholds 3 dB lower than clinical MEMR thresholds	Identification of WAI MEMR better in higher-frequency range in infants, lower-frequency range in adults (no comparison to clinical MEMR)	Group 1 (adults): Average WAI MEMR thresholds 2.2–4.0 dB lower than clinical MEMR thresholds Group 2 (children): No significant differences	Median low-frequency WAI MEMR 24 dB higher in infants who referred vs. passed screening

MEMR, middle ear muscle reflex; WAI, wideband acoustic immittance.

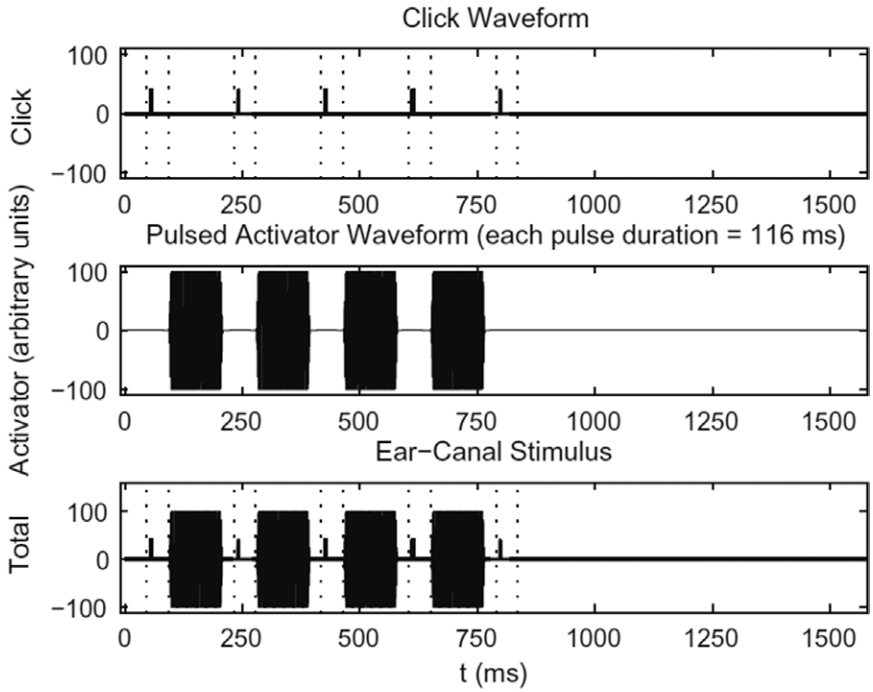

Fig. 1. In the Keefe et al. (2010) middle ear muscle reflex procedure, the click probe is presented through receiver 1 (top row) and the pulsed activator is presented through receiver 2 (middle row) alternately with the clicks. The bottom row shows the combined presentation of the probe and activator, and the dashed lines show the analysis window around each click probe. (Reprinted with permission from *Hearing Res* 2010; 263: 54.)

WAI FOR INFANT MEMR MEASUREMENTS

Wideband MEMR measurements have potential for use in newborn hearing screenings because they can be made without pressurization of the ear canal, and because objective decision rules for MEMR identification can be used in the data collection software. Such objective decision rules could be used in automated systems used by nonaudiological personnel. Another advantage of the broadband response is that changes in WAI in the presence of the activator can be observed regardless of the frequency range of maximum shift, which can be affected by age and middle ear status. For example, Feeney and Sanford (2005) found that the best frequency range over which to detect a wideband contralateral MEMR, elicited with a broadband noise, was 250 to 2000 Hz for adults, and 1000 to 8000 Hz for 6-week-old infants. With better detection of the MEMR and objective, automated protocols for newborn hearing screening, infants could be screened for both cochlear and retrocochlear involvement with one probe insertion using a system that has middle ear, OAE, and MEMR tests. Such a protocol would potentially identify infants in the well-baby nursery who may have auditory neuropathy and otherwise would be missed by an OAE-only screen. Individuals with auditory neuropathy often have present OAEs and absent MEMR and auditory brainstem responses (Hood 1999; Berlin et al. 2005).

Keefe et al. (2010) used a wideband tympanometer and an improved detection algorithm to identify the MEMR in a larger sample of newborn infants. In their method, the activator was pulsed and alternated with the click probe as shown in Figure 1, and a maximum likelihood technique in two frequency ranges (low and high) was used to detect the MEMR. They found that a combination of WAI tests of middle ear function and wideband MEMR tests could be used to predict newborn hearing screening outcomes. For further discussion of wideband MEMR measurements in infants, please see Hunter et al. (this issue, pp. 36S–42S).

NEED FOR FURTHER RESEARCH AND FUTURE DIRECTIONS

Wideband MEMR measurements have the same potential for clinical use as their pure-tone probe counterparts. Early studies suggest that WAI measures of MEMR may result in lower reflex thresholds. However, more normative data are needed for ipsilateral and contralateral WAI MEMR thresholds in adults and children with varying degrees of hearing loss. In addition, because WAI changes as a function of age in infancy (see Kei et al., this issue, pp. 17S–26S) and may change in the elderly (Feeney & Sanford 2004), the effect of age on WAI MEMR thresholds must be examined. Most of the available WAI MEMR data were collected with nonpressurized ear canals whereas 226 Hz probe measurements are typically made at TPP. More data are needed on WAI measurements of MEMR thresholds at ambient and TPP. There are currently no data available for WAI MEMR decay tests. Studies that include ears with retrocochlear pathology are required to estimate sensitivity and specificity of WAI MEMR threshold and decay tests for separating ears with cochlear from retrocochlear pathology. Finally, automated systems with objective detection of WAI MEMR thresholds could be developed for use by nonaudiological personnel in newborn hearing screening programs and by audiologists to save time during standard hearing evaluations.

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REFERENCES

American National Standards Institute. (2012). Specifications for instruments to measure aural acoustic impedance and admittance (aural acoustic immittance) (ANSI S3.39–1987–R2012). New York, NY: American National Standards Institute.

Arriaga, M. A., & Luxford, W. M. (1993). Impedance audiometry and iatrogenic hearing loss. *Otolaryngol Head Neck Surg*, *108*, 70–72.

Berlin, C. I., Hood, L. J., Morlet, T., et al. (2005). Absent or elevated middle ear muscle reflexes in the presence of normal otoacoustic emissions: A universal finding in 136 cases of auditory neuropathy/dys-synchrony. *J Am Acad Audiol*, *16*, 546–553.

Feeney, M. P., & Keefe, D. H. (1999). Acoustic reflex detection using wide-band acoustic reflectance, admittance, and power measurements. *J Speech Lang Hear Res*, *42*, 1029–1041.

Feeney, M. P., & Keefe, D. H. (2001). Estimating the acoustic reflex threshold from wideband measures of reflectance, admittance, and power. *Ear Hear*, *22*, 316–332.

Feeney, M. P., Keefe, D. H., Marryott, L. P. (2003). Contralateral acoustic reflex thresholds for tonal activators using wideband energy reflectance and admittance. *J Speech Lang Hear Res*, *46*, 128–136.

Feeney, M. P., Keefe, D. H., Sanford, C. A. (2004). Wideband reflectance measures of the ipsilateral acoustic stapedius reflex threshold. *Ear Hear*, *25*, 421–430.

Feeney, M. P., & Sanford, C. A. (2004). Age effects in the human middle ear: Wideband acoustical measures, *J Acoust Soc Am*, *116*, 3546–3558.

Feeney, M. P., & Sanford, C. A. (2005). Detection of the acoustic stapedius reflex in infants using wideband energy reflectance and admittance. *J Am Acad Audiol*, *16*, 278–290.

Gelfand, S. A. (2009). The acoustic reflex. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed.). (pp. 189–221). Baltimore, MD: Williams & Wilkins.

Hirsch, J. E., Margolis, R. H., Rykken, J. R. (1992). A comparison of acoustic reflex and auditory brain stem response screening of high-risk infants. *Ear Hear*, *13*, 181–186.

Hood, L. J. (1999). A review of objective methods of evaluating auditory neural pathways. *Laryngoscope*, *109*, 1745–1748.

Hunter, L. L., Ries, D. T., Schlauch, R. S., et al. (1999). Safety and clinical performance of acoustic reflex tests. *Ear Hear*, *20*, 506–514.

Kankkunen, A., & Lidén, G. (1984). Ipsilateral acoustic reflex thresholds in neonates and in normal-hearing and hearing-impaired pre-school children. *Scand Audiol*, *13*, 139–144.

Keefe, D. H., Fitzpatrick, D., Liu, Y. W., et al. (2010). Wideband acoustic-reflex test in a test battery to predict middle-ear dysfunction. *Hear Res*, *263*, 52–65.

Keefe, D. H., Ling, R., Bulen, J. C. (1992). Method to measure acoustic impedance and reflection coefficient. *J Acoust Soc Am*, *91*, 470–485.

Mazlan, R., Kei, J., Hickson, L., et al. (2007). High frequency immittance findings: Newborn versus six-week-old infants. *Int J Audiol*, *46*, 711–717.

Mazlan, R., Kei, J., Hickson, L. (2009). Test-retest reliability of the acoustic stapedial reflex test in healthy neonates. *Ear Hear*, *30*, 295–301.

McMillan, P. M., Bennett, M. J., Marchant, C. D., et al. (1985). Ipsilateral and contralateral acoustic reflexes in neonates. *Ear Hear*, *6*, 320–324.

Miller, M. H., Hoffman, R. A., Smallberg, G. J. (1984). Stapedial reflex testing and partially reversible acoustic trauma. *Hearing Instrum*, *35*, 15, 49.

Schairer, K. S., Ellison, J. C., Fitzpatrick, D., et al. (2007). Wideband ipsilateral measurements of middle-ear muscle reflex thresholds in children and adults. *J Acoust Soc Am*, *121*, 3607–3616.

Sprague, B. H., Wiley, T. L., Goldstein, R. (1985). Tympanometric and acoustic-reflex studies in neonates. *J Speech Hear Res*, *28*, 265–272.

Weatherby, L. A., & Bennett, M. J. (1980). The neonatal acoustic reflex. *Scand Audiol*, *9*, 103–110.