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Electrically Evoked Stapedial Reflex Threshold: A Procedure

Jessica J. Messersmith

Lavin Entwisle

Agelia Stout

University of South Dakota
Vermillion

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Objective measures, such as the electrically evoked stapedial reflex threshold (ESRT), are critical components of optimal cochlear implant (CI) programming. Recent data suggest, however, that ESRT measurements are not commonly used by audiologists when programming CIs (Hemmingson & Messersmith, 2017). Potential reasons for limited use of these measures may be limited knowledge of the procedure for completing the measures and limited knowledge of how to apply results to programming. Clinically, ESRT is observed as a change in the static admittance of the ear canal in response to electrical stimulation through the CI; this deflection can be observed using the decay setting on an immitance bridge. ESRT is defined as the lowest amount of electrical stimulation that results in a 0.02 deflection from baseline (Gelfand, 2002). ESRT has been found to align closely to behaviorally measured C/M levels and, as such, can assist in determining appropriate C/M levels during programming (Lira de Andrade et al., 2014; Stephan & Welzl-Müller, 2000). The purpose of this article is to describe a procedure for completing and applying ESRT measures, an objective measure that correlates to C/M levels, to CI programming.

A primary goal of cochlear implant (CI) programming is to establish an electrical dynamic range that provides adequate speech perception and is perceived as comfortable to the listener (Shapiro & Bradham, 2012). Optimal programming of a CI involves a combination of both objective measures and psychophysical measures of loudness. Objective measures include assessment tools that do not require any psychophysical or behavioral input from the listener. Through use of objective measures, judgments can be made about how the CI and physiology of the auditory system are working together. In terms of device programming, objective measures can be useful for programming devices for children or other individuals who may struggle to provide reliable psychophysical loudness judgments (e.g., Lira de Andrade et al., 2014; Wolfe & Schafer, 2017). The electrically evoked stapedial reflex threshold (ESRT) is one objective measure that can contribute to device programming. Recent data suggest, however, that ESRT is not widely used among audiologists. For example, over 50% of audiologists who work with pediatric CI users report never using ESRT measures (Hemmingson & Messersmith, 2017). These same data indicate that audiologists who work with pediatric CI users primarily receive their training related to CIs from on-the-job training. Therefore, it is plausible that one factor leading to limited use of ESRT is limited of knowledge in how to perform and apply the measures. As such, the purpose of this article is to describe ESRT, provide a procedure for measuring ESRT with CIs, and discuss the clinical application. Other objective measures, such as the electrically evoked compound action potential and electrically evoked auditory brainstem response are not discussed. These measures are worthy of a similarly styled discussion on their own. This article will begin with a background of ESRT and conclude with clinical application of ESRT measures.

ESRT: What Is It?

ESRT is an objective measure that is similar to acoustic reflex thresholds, where the static admittance of the ear canal (more specifically the contraction of the stapedius muscle) is monitored in response to varying amounts of sound input delivered through the CI. ESRT has been shown to be a helpful tool in CI programming, specifically in predicting a patient's upper stimulation (C/M) levels, and has been shown to remain stable/consistent over time postoperatively (Gross, 2003; Hodges et al., 1997; Jerger, Fifer, Jenkins, & Mecklenberg, 1986; Kosaner, Anderson, Turan, & Delibl, 2009; Lira de Andrade et al., 2014; Lorens, Walkowiak, Piotrowska, Skarzynski, & Anderson, 2004; Polak, Hodges, King, Payne, & Balkany, 2006; Stephan & Welzl-Müller, 2000; Wolfe & Kasulis, 2008). Previous studies have suggested that ESRT measurements fall within a similar range, or slightly above, a patient's psychophysical loudness judgments of upper stimulation (C/M) levels (e.g., Han et al., 2005; Spivak & Chute, 1994; Stephan & Welzl-Müller, 2000; Walkowiak et al., 2011). However, ESRT cannot be measured in all CI users; it is currently estimated that ESRT is not measurable in approximately 20%–30% of patients (Hodges et al., 1997; Spivak & Chute, 1994; Van Den Abbeele et al., 2012). Now, there is no clear understanding as to why patients may or may not have a measurable ESRT. One potential factor contributing to absent ESRT is injury to the stapedial muscle during surgery. Other instances where an ESRT is not measurable include when a patient has abnormal tympanograms, has facial nerve involvement, is unable to sit still, or cannot tolerate the level of the stimulation tone required to record a response (Stephan & Welzl-Müller, 2000). Wolfe et al. (2016) was the first published report of the effect of probe tone frequency to record an ESRT response. Results from Wolfe et al. (2016) suggested that higher probe tone frequencies (e.g., 1000 Hz) may be better able to record an ESRT response; however, the clinical implications (i.e., relationship of ESRT to C/M level) of these findings are still unknown.

Despite the research available citing ESRT as a potential predictor of upper stimulation level, a survey of currently practicing audiologists has revealed that ESRT is rarely used in the clinical setting (Hemmingson & Messersmith, 2017). Anecdotally, clinicians reported not using ESRT because they were not comfortable and/or familiar with the procedures for measuring ESRT. Therefore, the remainder of this article outlines the equipment, setup, and procedure necessary for measuring ESRT. (For an abbreviated outline, please see Table 1 and Figure 1).

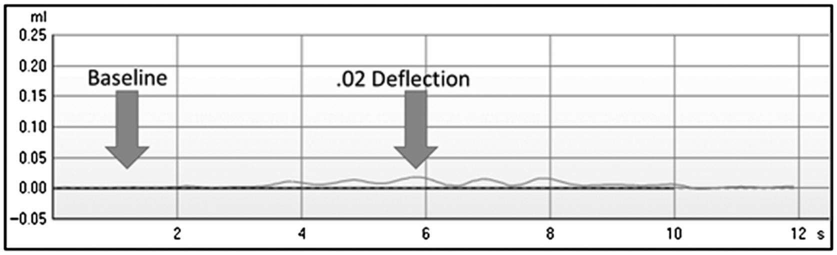
Table 1. Equipment and set-up for conducting ESRT measures.

Equipment	**Setup**

• All external components of the patient's CI (sound processor, cable, headpiece)
• Computer with CI manufacturer software
• CI programming cables
• CI software
• Immittance bridge with a reflex decay protocol
  • If immittance bridge is PC based, we additionally need:
    • Cables connecting the immittance bridge to the computer
    • Immittance bridge manufacturer software
• Immittance bridge probe tip of appropriate size for CI user's ear
	• Connect CI external components as one would for programming
	  • CI sound processor connected to programming cables, programming interface, and computer with CI software
	  • Patient wearing CI
	  • CI software open to patient's program file
	    • Enter screen where C/M levels would be measured
	• Probe tip attached to immittance bridge inserted into contralateral ear
	  • Ipsilateral also possible
	  • Foam tip on contralateral stimulus cable is not placed in the patient's ear
	• Immitance bridge set to an appropriate test (Note: procedure discussed below assumes decay/ESRT)
	  • Contralateral decay
	    • Extend recording window to 15–20 s
	  • ESRT
	  • Eustachian tube function

Note. ESRT = evoked stapedial reflex threshold; CI = cochlear implant; PC = personal computer.

Figure 1. Sample evoked stapedial reflex threshold tracing.



ESRT: Equipment, Setup, and Procedure

As stated previously, ESRT is measured through monitoring changes in the static admittance of the ear canal, which would indicate a stiffening of the ossicular chain (and, thus, a reflex response from the stapedius muscle) in response to varying amounts of the electrical stimulation through the implant (Shapiro & Bradham, 2012). When recording an ESRT, a primary requirement is that a long recording/viewing window be utilized to allow for monitoring of changes in the static admittance across the time period stimulation is provided to the CI. As such, clinically, the contraction of the stapedius muscle can be monitored through either an acoustic reflex decay measure or a eustachian tube function (ETF) test. Protocols for these measures exist on most immitance bridges. In addition, some models of immitance bridge are available with an ESRT test option; this setup typically uses the reflex decay and ETF tests. The procedure discussed here will reference ESRT measures completed via ESRT/reflex decay, not ETF.

Equipment and Setup

When setting up to complete ESRT measures, all equipment (provided in Table 1) must first be collected. The CI user can be set up as would be done during CI programming, where the CI sound processor will be connected to the manufacturer-specific software via a computer, programming interface, and programming cable(s) (cable connecting the interface to the computer and cable connecting the interface to the sound processor). The CI sound processor will be placed on the patient, with the head piece in the appropriate position over the internal receiver, and the sound processor will be placed on the body (ear or body based upon sound processor style). All of the patient's internal and external CI components, along with CI manufacturer-specific programming equipment and cables, should be checked prior to measurement to ensure proper function. ESRT measures may not be measurable if equipment is not functioning, and if measures are obtained with dysfunctional equipment, their interpretation could be limited.

A recording probe attached to an immittance bridge is inserted into the patient's ear. The probe can be placed and, therefore, ESRT measures obtained, in either the ear contralateral or ipsilateral to the CI. Acoustic reflex thresholds have been shown to differ by approximately 5 dB between ipsilateral and contralateral measurement when stimulated acoustically (Wiley, Oviatt, & Block, 1987). It is possible that a similar difference exists between ipsilateral and contralateral measure of acoustic reflexes when stimulated electrically. Publications evaluating the relation between ESRT and behavioral loudness judgments of C/M levels have historically been completed with a contralateral measure. Therefore, the relationship between ESRT and C/M level for ESRT measures obtained ipsilaterally may not be consistent with previous publications. (The relationship/agreement range between ESRT and C/M level is discussed in the "Applying ESRT to CI Programming" section below.) Regardless of the placement of the probe, ipsilateral, or contralateral, the reflex decay protocol on the immitance bridge should be set to a contralateral response. Further, the foam tip and stimulus transducer for the immitance bridge should not be placed in the individual's ear; only the probe casing is placed in the ear. Use of the contralateral setting and absence of the stimulus transducer on the immitance bridge are necessary so that stimulation is not presented through the immitance bridge. For ESRT measures, the immitance bridge is used for measurement of the contraction of the stapedial muscle; stimulation is provided via the CI and CI programming software.

Additionally, depending on the immittance bridge used to complete the ESRT measurement, manufacturer software may be available to use on the same laptop housing the CI manufacturer software. However, the immittance bridge software is not required. The clinician can choose to monitor the admittance tracings of the ear canal on the immittance bridge itself, if available.

One strength of ESRT recordings is that measures can and should be obtained using the exact same stimulus parameters in the CI software that would be used for behavioral loudness judgments. Thus, ESRT recordings can be obtained using channel specific stimulation (e.g., tone burst presentation using biphasic pulses) or for groups of electrodes (e.g., speech burst stimuli, where four adjacent electrodes are presented with bandpass-filtered white noise stimuli simultaneously), depending on device manufacturer and how behavioral loudness judgments are measured during the programming session. The ability to elicit ESRT with the same stimulus as is used for behavioral loudness judgment may be one reason for their high agreement with behavioral loudness judgment of C/M measures (Brickley et al., 2005; Hodges et al., 1997; Lorens et al., 2004).

Measurement Procedure

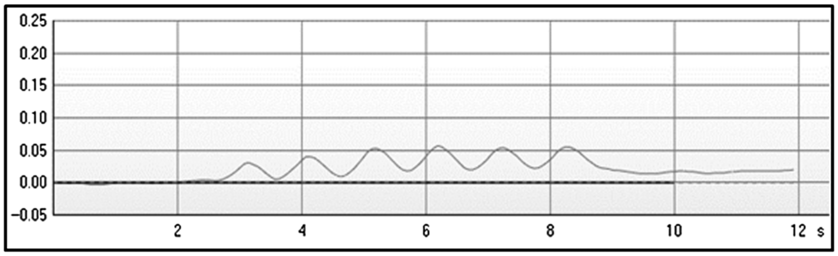
A prerequisite for measurement of acoustic reflexes is a typically functioning middle ear system. As such, middle ear mobility must be evaluated through a tympanogram prior to initiating ESRT measures. If the tympanometric measure indicates restricted middle ear mobility, ESRT measures should be discontinued as results cannot be interpreted. In addition, because ESRT recordings are a measure of the changes to the static admittance of the ear canal, it is sensitive to patient movement. So the patient must remain still and quiet during the measurement procedure. Patient movement can result in deflections in the ESRT tracing that can mask or be mistaken as an ESRT response.

Upon verifying middle ear mobility and instructing the listener to remain still, ESRT measurement can commence. As stated previously stated, this is based upon use of the ESRT/reflex decay test on the immitance bridge. The ESRT/reflex decay test will allow the clinician to use the immittance bridge to observe changes in the static admittance of the ear canal, which would indicate a contraction of the stapedial muscle as electrical stimulation is provided to the auditory system through the CI. To observe this change in static admittance, the recording in the immitance bridge must be started prior to the initiation of the stimulus in the CI software.

Once the recording window begins, a stable baseline admittance must be observed. A stable baseline is needed as reference for judgment of deflection in the static admittance when stimulation is initiated in the CI software. The deflection representing the ESRT response will be a deflection from baseline visualized either on the immittance bridge itself or in the immittance bridge software that is time locked to the onset and offset of the electrical stimulation provided in the CI manufacturer software (Wolfe & Schafer, 2010). It is important to note that the stable baseline may not fall at 0 ml on the recording window. A stable baseline is simply a relatively flat static admittance that can be used as a reference for the deflection. Figure 1 provides an example of an ESRT recording, demonstrating the stable baseline and the ESRT deflection.

Changes to the current level provided to the auditory system are achieved through manipulation in the CI software. In other words, the time-locked ESRT deflection should change in amplitude with respect to changes in stimulation level in the CI software. Thus, an increase in stimulation level in the CI software should result in an increase in amplitude of the ESRT deflection; a reduction in the stimulation level in the CI software should result in a decrease in the amplitude of the ESRT deflection. An example of an increase amplitude ESRT response is provided in Figure 2. The deflection represented in Figure 2 is larger than the deflection in Figure 1. This difference in the amplitude of deflection results from a higher stimulation level from the CI for the response represented in Figure 2 as compared with the response represented in Figure 1.

Figure 2. Sample evoked stapedial reflex threshold tracing demonstrating an increase in the depth of deflection, as compared with the deflection noted in Figure 1, resulting from an increase in stimulation level.

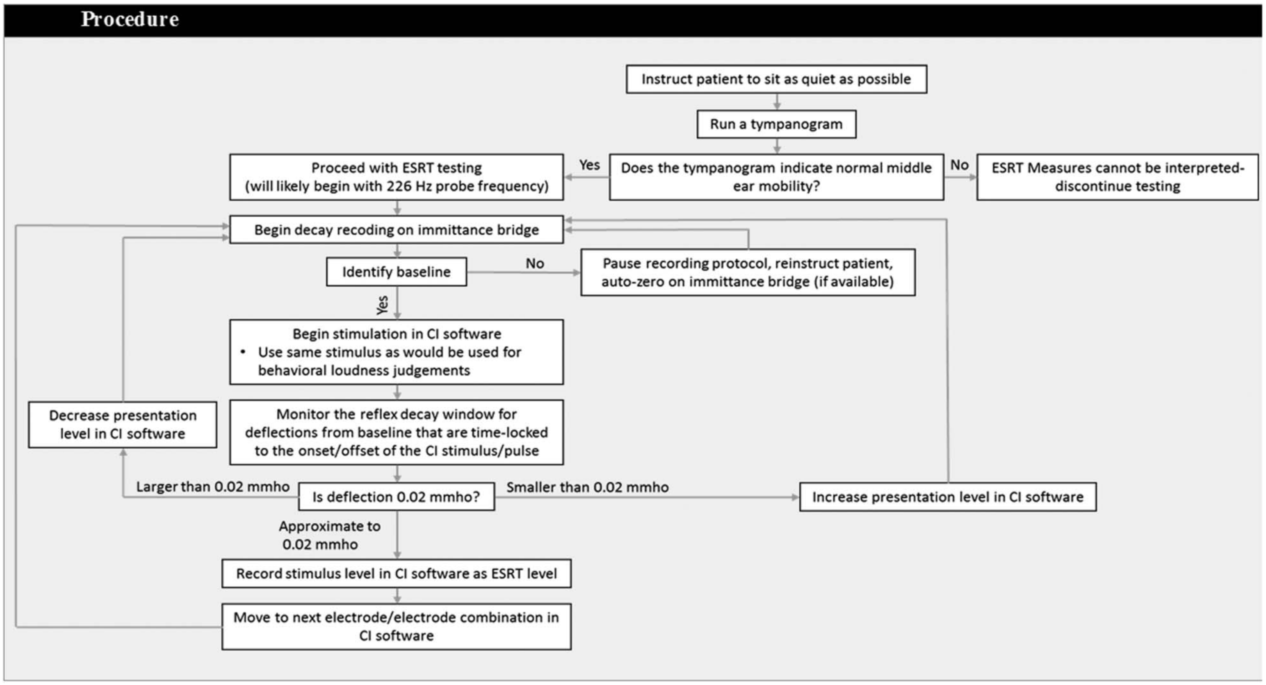


Given the relationship between ESRT and behaviorally measured C/M levels, a reasonable presentation level to begin measuring ESRT would be at the C/M level of the stimulating electrode in the patient's current MAP. Changes to the current level at the stimulating electrode can be made similarly to methods used for measuring behavioral thresholds. The lowest level of electrical stimulation presented via the CI software that elicits a repeatable 0.02 deflection from baseline is considered the threshold for an acoustic reflex (Gelfand, 2002). The stimulation level in the CI software at threshold (0.02 deflection on the immitance bridge) would be recorded for the stimulating electrode(s).

Finally, as would be done for behavioral loudness judgments, ESRT measures should be obtained at multiple points along the electrode array to account for variation in stimulation (C/M) levels across electrodes (Walkowiak et al., 2011). A goal of the CI program is balanced loudness across electrodes. Measurement of multiple points along the electrode array may provide for improved loudness balance. For example, one previous study has suggested that equal loudness may be perceived when upper stimulation levels reflect ESRT measures (Hodges et al., 1997). Further, electrode-specific programming of upper stimulation levels has been shown to result in improved outcomes in CI users (Plant et al., 2005).

As mentioned previously, ESRT is affected by physical noise, making measuring ESRT more difficult in pediatric populations or those who cannot sit still for periods of time. ESRT measurements also require normal middle ear function in order to reliably interpret a response. Therefore, it may be necessary to attempt ESRT measurements across multiple appointments in order to obtain reliable information across the electrode array. A decision diagram for the complete ESRT procedure is provided in Figure 3.

Figure 3. Decision diagram for ESRT procedure. ESRT = evoked stapedial reflex threshold; CI = cochlear implant.



Applying ESRT to CI Programming

ESRT levels can assist in establishing upper (C/M) levels of the electrical dynamic range across the electrode array for individuals with a CI (Gordon, Papsin, & Harrison, 2004; Gross, 2003; Hodges et al., 1997; Jerger et al., 1986; Kosaner et al., 2009; Lira de Andrade et al., 2014; Lorens et al., 2004; Polak et al., 2006; Stephan & Welzl-Müller, 2000; Wolfe & Kasulis, 2008). Behavioral loudness judgments are still considered the gold standard and are therefore an integral component of programming a CI. However, individuals with hearing loss may have difficulty making loudness judgments or describing the input they receive from their implant (Wolfe & Schafer, 2010). In these cases, the use of ESRT levels may be beneficial to set upper stimulation (C/M) levels, followed by adjustments to C/M levels based upon a patient's psychophysical judgments of loudness if/when appropriate (e.g., loudness balancing). Previous research has shown that ESRT measurements typically fall very closely to C/M obtained via behavioral loudness judgments (e.g., Gordon et al., 2004; Spivak, Chute, Popp, & Parisier, 1994). This application of ESRT, in combination with behavioral loudness judgments, may allow for more efficient programming methods. In addition, ESRT may serve as a guide for setting progressive MAPS (when applicable) to avoid overstimulation (Lira de Andrade et al., 2014). In addition, ESRT measures can be used as a cross-check of behavioral loudness judgments for confirmation of C/M levels.

Using a combination of ESRT and behavioral measures can be especially helpful when programming children or difficult to test populations where psychophysical input from the patient is considered unstable or unreliable (Lira de Andrade et al., 2014). ESRT can be especially helpful for children who are still learning the concept of loudness. However, there may be certain populations for whom this approach may not be suitable, for example, individuals with facial nerve stimulation or those with neurologic impairment. Those with facial nerve stimulation may not be able to achieve adequate loudness growth and may not be able to utilize C/M levels at

ESRT due to facial stimulation; however, changes to stimulus parameters in the CI can be made to address facial stimulation as would be done during behavioral loudness judgments. Individuals with neurologic impairment may have a difficulty with behavioral loudness judgments of C/M due to steep loudness growth functions. These unique cases require consideration regarding what deviations from the typical CI programming procedures are necessary to help optimize programming for these patients. As such, the audiologist should use their best clinical judgment to make appropriate modifications on a case-by-case basis. Future research is needed to understand the relationship between ESRT and C/M level in various subgroups of the population who utilize CIs.

Conclusion

ESRT is a useful tool for CI audiologists, especially when programming individuals who do not demonstrate the capacity to make reliable psychophysical loudness judgments. The discussion of the needed equipment, setup, and procedures for conducting ESRT provided in this article provide a framework for CI audiologists to increase their comfort with conducting, interpreting, and applying ESRT during CI programming. Inclusion of ESRT measurements as a part of the CI programming protocol may help audiologists meet the growing demands of establishing more efficient CI programming methods, increase confidence of appropriateness of CI programming, and assist in the creation of individual optimal CI MAP parameters.

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