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The CON-SOT-LOT Test for Nonorganic Hearing Loss

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Abstract

The efficacy of a screening procedure for detecting nonorganic hearing loss using standard audiometric instrumentation was examined. Thirty normal-hearing subjects' responses to continuous and standard and lengthened off-time pulsed tones, using an ascending-descending method, were compared. Subjects were asked to respond to test stimuli in normal-hearing and simulated hearing loss conditions. Data show that there are clinical and statistical differences between subjects' response patterns in the normal-hearing condition as compared to the feigned hearing loss condition. The procedure is offered as a simple method of screening for nonorganic hearing loss.

Key Words: Ascending-descending method, nonorganic hearing loss, screening procedure

Abbreviations: A-D = ascending-descending, ANOVA = analysis of variance, CON = continuous tone, LOT = lengthened off-time pulsed tone, MML = modified method of limits, NOHL = nonorganic hearing loss, STL = simulated threshold level, SOT = standard off-time pulsed tone

Following the introduction of the Type V Békésy pattern by Jerger and Herer in 1961, which showed more hearing loss for pulsed tones than for continuous tones, modifications of Békésy audiometry emerged, aiding in the detection of nonorganic hearing loss (NOHL). Hood et al (1964) proposed the Békésy Ascending Descending Gap Evaluation (BADGE) to examine intensity-change directionality in Békésy audiograms. Using this procedure, significant gaps (>4 dB) between ascending and descending tracings (A-D) were reported to be indicative of NOHL. Hattler (1970) proposed the lengthened off-time (LOT) test based on his previous research (1968), suggesting that changes in duty cycle of the pulsed tones directly affected Type V patterns. This alteration (LOT) increased the number of Type V patterns in patients suspected of NOHL without affecting the Békésy tracings of patients with normal hearing or true organic hearing losses. Chaiklin (1990) confirmed Hattler's findings using a descending version of Hattler's LOT test, called DELOT.

Although Békésy audiometry generated plausible screening techniques for detecting NOHL, the limited availability of equipment, test complexity, and test administration time have contributed to its diminished utility during standard hearing evaluations. A recent survey of audiometric practices in the United States showed that only four percent of audiologists used some form of Békésy audiometry to assess NOHL (Martin et al, 1998a). Similarly, other reliable methods for identifying NOHL, such as auditory evoked potentials, otoacoustic emissions, and acoustic reflex threshold testing, pose limitations as viable screening procedures because of equipment needs and time constraints. These procedures also require changes in either transducer type or patient set-up, which ultimately disrupts the standard test protocol. Due to these limitations, easily performed screening methods using common audiometric equipment have appeal.

Harris (1958) evaluated the A-D gap using a modified method of limits (MML) and a basic

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clinical audiometer. Results with this technique showed significantly larger gaps between A-D thresholds for patients suspected of NOHL as opposed to those with true hearing losses. A-D gaps of 5 dB or more characterized NOHL. Cherry and Ventry (1976), using slightly different separation criteria (A-D gap >10 dB) to indicate a suprathreshold response, further validated the MML procedure.

Lankford and Meissner (1977) proposed a manual version of the LOT test. In order to simulate LOT pulsed tones, an audiometer with a continuously variable attenuator capable of producing the necessary 20 percent duty cycle was used. Average responses from manual LOT tones exceeding continuous tones by 5.5 dB or more suggested NOHL. Results with the manual LOT appear to be a useful modification of Békésy audiometry in screening for NOHL.

A screening approach comparing A-D gaps in NOHL using common audiometric equipment was proposed by Woodford et al in 1997. This method, like the Harris MML procedure (1958), differed from previous investigations in that only responses to continuously presented pulsed tones were compared. A-D differences of 10 dB or greater were reported as "unreliable," thereby indicating NOHL.

Despite apparent differences in test methodologies, studies using standard audiometric equipment for detecting NOHL lend support for its use as a viable alternative to Békésy audiometry in this endeavor. The extent to which techniques for identifying NOHL (Type V Békésy audiogram, A-D gap, and LOT) can be combined into one screening procedure using standard equipment has not been previously investigated and was the focus of the present research.

METHOD

Subjects

Subjects consisted of 30 English-speaking adults (9 males, 21 females), whose ages ranged from 20 to 27 years (mean = 22.3), with normal hearing sensitivity bilaterally. Normal hearing was defined as hearing thresholds lower than or equal to 15 dB HL from 250 to 8000 Hz (ANSI, 1996). Although concern has been raised about using normal-hearing subjects for the evaluation of NOHL, many studies have documented this practice (e.g., Cherry and Ventry, 1976; Mordaunt and Martin, 1976; Woodford et al, 1997; Martin et al, 1998b). Furthermore, it can be assumed that patients with true NOHL would be unwilling to volunteer their actual hearing thresholds for experiments like these.

Materials and Equipment

All audiometric testing was performed in a sound-treated room adhering to ANSI-1991 allowances for permissible ambient noise levels. A Madsen Orbiter 922 clinical audiometer, calibrated to ANSI-1996 specifications, was used for all testing procedures. Acoustic stimuli were presented through Telephonics TDH 39 audiometric headphones mounted in MX-41/AR cushions.

Signals

Three different acoustic stimuli were used during the procedure. In all cases, the audiometer was set to the "normally on" position:

1. A continuous tone (CON).
2. A pulsed tone with a standard off-time (SOT) (44.4% duty cycle; 200 msec on, 250 msec off). The slight difference between the duty cycle used here with previous studies using a 50 percent duty cycle was due to audiometer limitations.
3. A pulsed tone with a lengthened off-time (LOT) (22.2% duty cycle; 200 msec on, 700 msec off). LOT tones were achieved by manually depressing the interrupter switch between successive SOT pulsed tones. Thus, every other pulse was not presented to the subjects.

Test Procedure

In order to evaluate the sensitivity and specificity of the screening procedure (CON-SOT-LOT) to distinguish between threshold and suprathreshold responses, subjects received test stimuli under two separate hearing conditions. Subjects were initially asked to respond at threshold and then again by simulating a hearing loss. In order to parallel real-world test situations, subjects selected their own levels (in dB) for exaggeration of their thresholds.

In the normal-hearing task, signals (CON, SOT, and LOT) were monaurally presented at 1000 Hz in random order to each subject in both an ascending and descending method. Test ear was alternated across subjects (15 right, 15 left). The attenuator for all ascending tones was set to −10 dB HL, ensuring that the tones were initially presented below threshold. Conversely, the attenuator was initially set to relatively high intensities (90, 95, and 100 dB HL) for presentation of the descending tones. Audiometric thresholds were considered to be the intensity where subjects first indicated that a signal was heard (ascending method) or the intensity where subjects indicated that the signal was no longer present (descending method).

The attenuator was manipulated in 5-dB steps until thresholds were established. An attenuation rate of 2.2 dB/sec was estimated for SOT tones and 2.4 dB/sec for LOT tones. These values correspond to five pulses per intensity increment/decrement for SOT tones and three pulses per intensity increment/decrement for LOT tones. An attenuation rate of 2.5 dB/sec for CON tones was easily achieved with practice of the procedure.

In the feigned hearing loss condition, the attenuator was randomly set at 10, 20, or 25 dB HL for ascending tones, whereas starting intensities for descending tones were presented at 85, 95, or 100 dB HL. Alterations in starting level were made to offset any strategies used by subjects, such as counting "jumps" in loudness, or pulse-counting techniques, to arrive at a consistent response level. Besides modifications in starting levels, test protocol remained unchanged. Simulated threshold levels (STLs) were obtained and recorded in the same fashion as for the normal-hearing condition.

RESULTS

Subsequent to data collection, a 3 × 2 × 2 analysis of variance (ANOVA) was performed to determine whether significant differences ($p < .05$) existed between subjects' true thresholds and STLs. In this design, test variables of signal type (CON, SOT, and LOT) and approach mode (ascending and descending) were evaluated with regard to responses obtained across both hearing tasks.

Overall results of the ANOVA (Table 1) indicated that subject response patterns in the normal-hearing condition were significantly different from their STLs in the exaggerated hearing loss condition. Moreover, approach mode appeared to largely influence subject responses. Although interaction was noted in the analysis of signal type, due to the fact that all signals were presented in both hearing conditions, a clear assessment of signal type, hearing task, and approach mode within this statistical design may have obscured the differences between them.

A main supposition regarding subject responses during threshold measurement was that signal type and approach mode should have minimal effects (≤10-dB range) on true hearing thresholds. In this study, all but seven subjects met this general assumption. Curiously, all seven subjects demonstrated a decrease in hearing sensitivity for continuously presented tones in a descending method (CON D). In order to determine whether these findings occurred as a result of abrupt-onset, high-intensity tones (90–100 dB HL), a CON D with a 50 dB HL starting intensity (CON D-50) was administered to these seven subjects prior to the acquisition of remaining thresholds. When using CON D-50 signals, thresholds for these seven subjects were within the predicted range.

In order to evaluate subject response patterns in each hearing condition independently, two separate 3 × 2 ANOVAs were performed. Results of the ANOVA on true thresholds (Table 2) revealed that signal type and approach mode, when evaluated independently, had no significant effect on hearing thresholds, but a collective comparison of signal and approach did. Although statistically different, this later comparison was still considered to be clinically reliable (≤10-dB range). Results of the ANOVA on subject STLs (Table 3) showed that both approach mode and signal type significantly

Table 1 Results of the 3 × 2 × 2 ANOVA Comparing Signal Type and Approach Method of Subject Responses across Both Hearing Conditions

Source	*df*	*Sum of Squares*	*Mean Square*	*F Value*	*p Value*
Condition	1	229017.78	229017.78	8540.31	.0001
Approach	1	6336.61	6336.61	97.91	.0001
Condition *approach	1	4271.11	4271.11	66.03	.0001
Signal	2	218.75	109.38	0.20	.1859
Condition *signal	2	1225.97	612.99	9.48	.0001
Approach *signal	2	396.81	198.40	3.07	.0478
Approach *signal *condition	2	51.81	25.90	0.40	.0670

Table 2 Results of the 3 × 2 ANOVA Comparing Subject Responses in the Normal-Hearing Condition (with CON D-50 Thresholds)

Source	*df*	*Sum of Squares*	*Mean Square*	*F Value*	*p Value*
Approach	1	16.81	16.81	1.00	.3191
Signal	2	65.83	32.92	1.96	.1446
Signal *approach	2	111.94	55.97	3.32	.0383

affected subject response patterns when asked to simulate a hearing loss.

Subject STLs revealed that, with the exception of three cases, subject responses to ascending signals yielded significantly better thresholds (Fig. 1). Mean A-D gaps for the normal-hearing and exaggerated hearing loss conditions were 0.6 dB and 15.3 dB, respectively. Tukey post hoc analysis of signal type for STLs showed that LOT tones (mean = 60.25) were significantly different from CON tones (mean = 54.08), but SOT tones (mean = 58.08) were not significantly different from LOT or CON tones. Although the degree of separation between pulsed and continuous tones constituting the Type V pattern may be largely influenced by the A-D technique, STLs for descending SOT and LOT tones in this study did generally indicate poorer hearing than ascending CON tones (Fig. 2). Using a greater than 10-dB range criterion to indicate NOHL, the procedure was found to be 100 percent sensitive and 100 percent specific (with inclusion of CON D-50 thresholds) in the detection of NOHL.

DISCUSSION

The current investigation was proposed to assess the efficacy of a procedure requiring only standard audiometric equipment for the evaluation of NOHL. The results obtained in this study show that there are several test paradigms that, when used in concert, can assist in distinguishing between threshold and suprathreshold responses.

Based on results with the CON-SOT-LOT procedure, the use of both ascending and descending methods for detecting NOHL is supported. Based upon subject feedback, it appears that the A-D approach inhibits the use of strategies involving memorization of starting intensities for the signals. Difficulty with this task may have been compounded because different starting intensities were also used for each signal presentation.

Although subject STLs for LOT and SOT pulsed tones were not statistically different, the exclusion of either one of these tones would have decreased the sensitivity of the procedure below 100 percent. Therefore, the unique combination of manual SOT and LOT tones in this procedure proved to be beneficial.

In review of the results obtained in this study, slight elevations in normal-hearing thresholds were found for seven subjects when continuous tones were presented in a descending method (CON D). Therefore, adhering to a greater than 10-dB separation criterion indicating NOHL, inclusion of the CON D thresholds from these seven subjects would reduce the specificity of the procedure to approximately 77 percent. However, slight threshold shifts encountered during the normal-hearing condition would not explain the dramatic response inconsistencies observed for these subjects in the feigned hearing loss condition. Although an exact explanation for this phenomenon is difficult, due to the immediate improvement in subjects' thresholds to CON D tones using a lower starting intensity, auditory fatigue is possible but does

Table 3 Results of the 3 × 2 ANOVA Comparing Subject STLs

Source	*df*	*Sum of Squares*	*Mean Square*	*F Value*	*p Value*
Approach	1	10503.47	10503.47	96.14	.0001
Signal	2	1174.44	587.22	5.38	.0054
Signal *approach	2	87.78	43.89	0.40	.6698

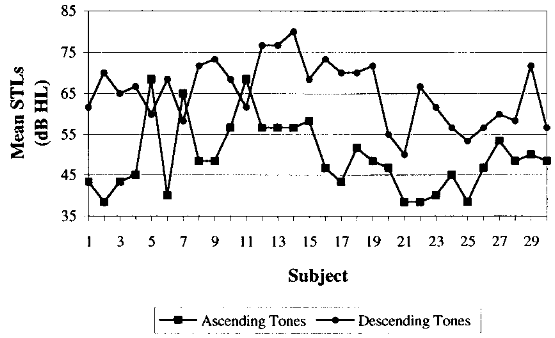

Figure 1 Mean STLs (for CON, SOT, and LOT) for ascending and descending tones. With the exception of three cases (subjects 5, 7, and 11), mean STLs for ascending tones revealed lower reported thresholds than did descending tones. Symbols are connected to demonstrate response patterns from subject to subject.

not, in any way, obviate the advantages of this procedure.

There are several key components to the administration of the CON-SOT-LOT procedure: (1) the use of all CON, SOT, and LOT tones; (2) the random presentation of signals in an A-D approach (also randomized); (3) variation in the starting intensities for both ascending and descending tones; and (4) different attenuation rates for each signal type. A key theme among these components is variation. If one assumes that patients with NOHL attempt to exaggerate hearing thresholds using strategies based upon the "pattern" of the test, then varying the test format would serve to decrease the margin of error in subject classification.

Because the procedure can be performed using virtually any audiometer and requires approximately 2 to 3 minutes to complete, its applicability as a screening tool for NOHL is evident. In most cases, the CON-SOT-LOT test can be discontinued when a positive finding for NOHL is observed. Administration of the CON-SOT-LOT test can also be performed in a variety of test environments. For example, the test could be used to screen for NOHL in children during school screenings as soon as this behavior is noted, followed by a repeat screening. Immediate performance of the CON-SOT-LOT test might discourage NOHL behavior and possibly eliminate the necessity for more in-depth testing.

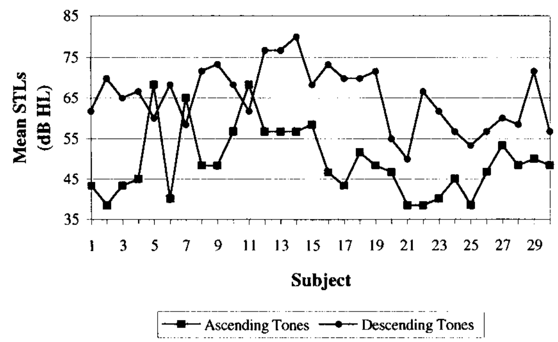

Figure 2 General pattern of poorer hearing for pulsed tones than continuous tones using the CON-SOT-LOT procedure. In all cases, the range of STLs for CON A, SOT D, and LOT D tones exceeded the >10-dB criterion selected to indicate a "reliable" response. Symbols are connected to demonstrate response patterns from subject to subject.

The CON-SOT-LOT test was not designed to produce an exact measurement of hearing status but rather to alert the clinician to the possibility of NOHL. However, some quantitative information can be inferred. In this study, 79 percent of the subjects showed lower STLs for ascending CON tones when compared to other signals. This finding is similar to that reported by Hood et al (1964). Additionally, it is logical to assume that the hearing loss is no greater than the lowest reported response at any frequency. Although the procedure was performed in this study using normal-hearing subjects, very similar results have been obtained on patients who were either fabricating or exaggerating a true hearing loss. In fact, to date, we have seen no patients who were able to defeat this procedure.

There is certainly no shortage of objective tests for both identifying and quantifying nonorganic loss. But these tests will not be helpful unless the clinician's index of suspicion leads to the administration of such tests. There continues to be a role for a simple, easily administered screening tool appropriate for the initial stage of auditory evaluation. We suggest that the CON-SOT-LOT test can fill this role.

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