

Research Article

Effective Identification of Functional Hearing Loss Using Behavioral Threshold Measures

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Purpose: Four functional hearing loss protocols were evaluated.

Method: For each protocol, 30 participants feigned a hearing loss first on an audiogram and then for a screening test that began a threshold search from extreme levels (−10 or 90 dB HL). Two-tone and 3-tone protocols compared thresholds for ascending and descending tones for 2 (0.5 and 1.0 kHz) and 3 (0.5, 1.0, and 2.0 kHz) frequencies, respectively. A noise-band protocol compared an ascending noise-band threshold with that for 2 descending tones (0.5 and 1.0 kHz). A spondee protocol compared an ascending spondee threshold with that for 2 descending tones (0.5 and 1.0 kHz). These measures were repeated without the participants feigning losses.

Results: With nonfeigning participants, ascending and descending threshold differences were minimal for all protocols. When the participants feigned a loss, the spondee protocol produced the largest average threshold difference (30.8 dB), whereas the other protocols produced smaller differences (19.6–22.2 dB).

Conclusions: Using both the screening test and a comparison of the initial audiogram with the screening test, the spondee and 3-tone protocols resulted in 100% true positives and 0% false positives for functional hearing loss. Either of these protocols could be used clinically or in occupational hearing conservation programs.

Functional hearing loss is a false elevation of hearing that cannot be explained as a known organic disorder (Ventry & Chaiklin, 1965). This condition, also known as *pseudohypacusis* or as *nonorganic hearing loss*, is diagnosed based on intra- and intertest inconsistencies. Although most persons presenting with functional hearing loss are feigning a loss, others have a subconscious cause (Wolf, Birger, Shoshan, & Kronenberg, 1993). This latter condition is rare, and the distinction between the conscious and unconscious etiologies cannot be determined using audiometric tests.

Most clinical and all occupational audiology settings are presented with cases of functional hearing loss. The prevalence in clinical populations ranges from 1% to 5% (Rintelmann & Schwan, 1991). The prevalence is higher among persons who can benefit from the loss, such as ones seeking monetary compensation.

The role of the clinical audiologist is to identify a functional hearing loss if present, quantify actual hearing capability, and, when necessary, refer the person for medical evaluation and/or psychological counseling. Although many special tests have been developed specifically for identifying functional hearing loss, most audiologists rely on the cross-check principle inherent in their standard clinical test battery, which mainly assesses consistencies among threshold measures for tones and for speech. For bilateral functional hearing loss, which makes up two-thirds or more of the cases (Gelfand & Silman, 1993), audiologists rely on measures such as test–retest thresholds at 1.0 kHz and the agreement between the pure-tone average (PTA) and the spondee threshold (ST). In persons not feigning a loss, these measures show close agreement. The retest of 1.0 kHz usually agrees within 10 dB of the first threshold (Schlauch & Carney, 2012; Shepherd, 1965). The ST also usually agrees within 10 dB of the average of thresholds for 0.5 kHz and 1.0 kHz or, in rising audiograms, 1.0 kHz and 2.0 kHz (Chaiklin & Ventry, 1965). In persons feigning a hearing loss, the ST is generally lower than the PTA (Carhart, 1952).

The strategy most often used by persons feigning a hearing loss involves adoption of a loudness “reference” (Conn, Ventry, & Woods, 1972; Gelfand & Silman, 1993). That is, persons feigning a loss usually use an internal loudness

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Editor: Nancy Tye-Murray

Associate Editor: Todd Ricketts

Received February 25, 2014

Revision received July 29, 2014

Accepted September 30, 2014

DOI: 10.1044/2014_JSLHR-H-14-0066

Disclosure: The authors have declared that no competing interests existed at the time of publication.

yardstick and will respond only to sounds that are perceived to exceed this internal reference level. A likely factor contributing to the ST–PTA difference is a natural loudness difference between a suprathreshold spondaic word and a suprathreshold tone of 0.5 kHz or 1.0 kHz due to *loudness summation*, a phenomenon that describes how cochlear filtering affects loudness growth. Broadband sounds, which stimulate multiple auditory filters, grow more rapidly in loudness with level than do narrow-spectrum sounds, such as pure tones. Consistent with this idea, the loudness of speech grows more rapidly than that of a tone. Speech and tones adjusted to produce equally loud percepts would result in the speech being at a lower sound pressure level (SPL) than that of a tone of 0.5 kHz or 1.0 kHz, the ones typically compared with the ST. This is consistent with the finding in persons who feign a hearing loss using an internal loudness reference in which the ST is, on average, lower than the tonal threshold (Carhart, 1952; Schlauch, Arnce, Olson, Sanchez, & Doyle, 1996).

The finding that most persons feigning a hearing loss adopt an internal loudness reference has been used as the basis for some tests for identifying functional hearing loss (Chaiklin, 1990; Harris, 1958; Schlauch et al., 1996). These tests use a discrepancy between “thresholds” (loudness judgments in persons feigning a loss) obtained for ascending (e.g., starting level –10 dB HL) and descending (e.g., starting level 90 dB HL) series. Persons feigning a loss show a significant discrepancy, whereas persons not feigning a loss show excellent agreement for thresholds obtained using the ascending and descending approaches (Chaiklin, 1990; Harris, 1958; Schlauch et al., 1996). This ascending–descending approach has been used successfully to maximize pure-tone threshold differences (Chaiklin, 1990; Harris, 1958) and ST–PTA differences in persons presenting with functional hearing loss (Schlauch et al., 1996).

Important considerations for evaluating the effectiveness of a test for functional hearing loss are its true-positive rate and its false-positive rate. The *true-positive rate* is defined as the probability that a person with functional hearing loss will be identified correctly by that test. By contrast, the *false-positive rate* is defined as the probability that a person who is not feigning a loss will be incorrectly (falsely) identified as presenting with functional hearing loss. An ideal diagnostic test is one that achieves a 100% true-positive rate and a 0% false-positive rate while at the same time being quick, easy to administer, inexpensive, and noninvasive.

Schlauch et al. (1996) found that STs measured using an ascending approach and tonal thresholds measured using a descending approach yielded a 100% true-positive rate and a 0% false-positive rate for identification of functional hearing loss when the pass–fail criterion represented an ST–PTA difference greater than 10 dB. The average ST–PTA difference in persons feigning a loss under these conditions was 41.6 dB. Other combinations of ascending and descending approaches were much less effective. Ascending tonal thresholds paired with a descending ST procedure (i.e., American Speech-Language-Hearing Association [ASHA], 1988) yielded only a 33% true-positive identification rate and, on

average, a 1.6-dB threshold difference. An ascending approach for both the pure-tone thresholds and the ST (ASHA, 1979) resulted in a 10-dB average threshold difference and a 60% true-positive identification rate.

In military hearing conservation programs for noise-exposed personnel, trained audiometric technicians usually administer the annual audiograms, often testing a group of people at the same time in the same room. Those individuals with persistently significant shifts in hearing to abnormal hearing levels are sent to occupational audiologists for a diagnostic evaluation. The ratio of military occupational audiologists to noise-exposed military members is small, and unnecessary referrals need to be minimized. In addition, the presence of a functional hearing loss on any particular test can result in repeated hearing test appointments, even before audiological referral, and time lost from work. Therefore, early identification of persons presenting with functional hearing loss is critical for effective resource management of financial and human resources.

An ST–PTA screening test for functional hearing loss, as suggested by Schlauch et al. (1996), represents a highly effective test, but because the U.S. Navy uses an automated PTA procedure and personnel are examined in groups in a single room, administration of a traditional ST that requires oral responses is not practical. A closed-set ST test could be a possible solution but would require more elaborate equipment for responding. A possible solution for this problem is to substitute a noise stimulus for the spondee words in the ST procedure. One goal of the present study was to examine this idea. The effectiveness of an ST–PTA screening test was compared with that of a screening test based on thresholds for a noise-band threshold obtained using an ascending procedure and pure tones obtained using a descending procedure.

A second goal of the current study was to compare the relative effectiveness of an ascending–descending ST–PTA procedure with that of an ascending–descending threshold procedure using tones alone. Harris (1958) completed the first major study that examined whether a discrepancy between ascending and descending pure-tone thresholds could be an effective test for identifying persons with functional hearing loss. The test was based on thresholds obtained at three frequencies: 0.5 kHz, 1.0 kHz, and 2.0 kHz. Harris (1958) found an average discrepancy of 26.8 dB between ascending and descending thresholds for persons feigning a hearing loss. His study did not compare true-positive and false-positive rates for a range of pass–fail criteria or for average three-frequency or two-frequency tonal thresholds. If the primary source of typical measurement variability for pure-tone thresholds is independent, averaging retest threshold differences from more frequencies should improve test precision. In the interest of developing a highly efficient test, we assessed whether testing with three pure-tone frequencies adds to the ability to identify functional hearing loss compared with two frequencies. We hoped to learn whether adding the third frequency improves the precision of the test enough to justify the added time it takes to make this measurement.

To compare the effectiveness of these approaches, a series of experiments was conducted using speech, tones, and noise bands in groups of persons asked to feign a hearing loss. The goal of these studies was to develop an effective and efficient test battery for detecting functional hearing loss in a clinical population.

Method

Participants

Adult participants were recruited through ads and were paid for their participation. The 120 participants were divided equally among four groups, which were named *noise-band protocol*, *spondee protocol*, *two-tone protocol*, and *three-tone protocol*. Most were university students and had hearing thresholds within normal limits (thresholds ≤ 25 dB HL at all audiometric frequencies), but two participants in the noise-band group, one participant in the spondee group, and one participant in the two-tone group had mild to moderate losses at 2.0 kHz or higher. Prior to participation, informed consent was obtained in accordance with a protocol approved by the Institutional Review Board at the University of Minnesota.

Stimuli and Instrumentation

An established psychoacoustic laboratory (a desktop computer along with custom-designed hardware including a digital-to-analog converter, manual attenuators, programmable attenuators, and filters) was programmed to perform like an audiometer. Tones (octave intervals between 0.25 kHz and 8.0 kHz) and a band-pass noise were generated using a 20-kHz sampling rate and output using a 16-bit custom digital-to-analog converter. The band-pass noise had cutoff frequencies of 0.5 kHz and 1.5 kHz. All stimuli were low-pass filtered at 8.0 kHz to prevent aliasing.

Pure-tone stimuli were 200 ms in duration. Three pulses were presented each time the tone was initiated by the experimenter. Noise stimuli were 2 s in duration, and only a single burst was presented. All nonspeech stimuli had 20-ms cosine-squared rise/fall times. The time between successive stimulus presentations was controlled by the experimenter. The experimenter considered that the test time needed to be quick but also avoided a rhythmic inter-stimulus presentation interval that would have been predictable to the listener.

For the spondee group, nine spondaic words were selected from the Q/Mass recording of spondees (Raffin & Thornton, 1988). The nine words, spoken by a man with a neutral American English accent, were *drawbridge*, *oatmeal*, *pancake*, *schoolboy*, *sidewalk*, *stairway*, *toothbrush*, *whitewash*, and *woodwork*. The spondaic words were stored on the desktop computer's hard drive and were presented through a custom 16-bit digital-to-analog converter. The sampling rate was 20.0 kHz, and these words were low-pass filtered at 8.0 kHz to prevent aliasing.

Pure-tone and speech stimuli were calibrated for level and exceeded the requirements for attenuator linearity,

overshoot, and harmonic distortion in accordance American National Standards Institute (ANSI) S3.6-2010. Stimuli were presented monaurally through earphones (TDH-39; Telephonics, Farmingdale, NY). Digitally controlled attenuators adjusted stimulus levels based on keyboard input to the microcomputer used to generate the stimuli. Participants listened in a double-walled, sound-attenuated room. The experimenter, located outside the booth, adjusted levels based on the listener's responses (raising a finger or their hand) that were observed through a window or on the correct or incorrect recognition of a spondaic word conveyed by the selection made on a keyboard.

Setting Audiometric Zero for the Noise Stimulus

Before actual data collection began, we obtained thresholds from eight young persons who had no history of ear disease and who had hearing within normal limits; we did this in order to establish audiometric zero for the noise stimulus. These persons were not participants in the experimental conditions. Thresholds were obtained using a method-of-limits procedure similar to the typical clinical procedure but with a smaller step size. When participants heard a stimulus presentation, the level was lowered by 4 dB. When a stimulus presentation didn't produce a response, the level was increased by 2 dB. Thresholds corresponded to the first level that produced a response on three ascending runs beyond the initial response. The median level of the noise stimulus at threshold was 10 dB SPL.

Procedure

Participants were tested individually. Each was instructed to feign a hearing loss using instructions (see Appendix) that were nearly identical to those in Schlauch et al. (1996). Thresholds were measured in each participant's right ear unless asymmetrical thresholds were reported in an initial interview. In that event, the participant's "better" ear was tested.

After instruction to feign a loss, an air-conduction audiogram (octave frequencies 0.25–8.0 kHz) was obtained under earphones for one ear using a standard procedure (ASHA, 1978). As is the convention, 1.0 kHz was tested twice for a measure of reliability. The starting level was 30 dB HL at each frequency. The stimulus was pulsed tones (200 ms with a 50% duty cycle). Thresholds were based on the lowest level that yielded responses on two ascending runs (Marshall & Hanna, 1989). This initial audiogram simulated the annual audiogram in Navy hearing conservation programs. Because thresholds were assumed to deviate significantly from the previous year's baseline audiogram (in our case because each participant was asked to feign a loss), a screening test for identification of a feigned hearing loss was administered immediately following the measurement of the audiogram. Participants were assigned to one of four protocols for the administration of the screening test: the noise-band protocol, the spondee protocol, the two-tone protocol, or the three-tone protocol.

In all cases, the tests with feigned hearing loss always preceded tests with unfeigned hearing loss. The reason for doing so rather than counterbalancing was to simulate the clinical situation where feigned thresholds trigger the functional hearing loss screening test.

Screening test for the noise-band group: Ascending band-pass noise thresholds versus descending tonal thresholds. Measurements were obtained using an ascending approach for the band-pass noise stimulus. The duration of each presentation was 2 s. An ascending approach was found to yield the largest differences in persons feigning a hearing loss in Schlauch et al.'s (1996) study when spondee words were used as the stimuli. For this threshold measurement, the starting level was -10 dB HL. The stimulus level was increased in 10-dB steps until a response was observed. Every response that coincided with a stimulus presentation resulted in a 10-dB reduction in the subsequent stimulus presentation level; failure to respond to a stimulus presentation resulted in a 5-dB increase in the stimulus level. The measured threshold corresponded to the first level that yielded two responses on ascending runs beyond the initial response.

Next, thresholds were measured using a descending approach for 0.5-kHz and 1.0-kHz tones. Three-tone bursts were presented for each stimulus presentation at a given level. The stimulus duration was 200 ms with an 800-ms off-time for descending runs. Chaiklin (1990) found that a lengthened off-time (20% vs. 50% duty cycle) for descending runs increased the threshold gaps of persons presenting with functional hearing loss. The starting level for each threshold search was 90 dB HL. The level was lowered in 10-dB steps until the participant did not respond. At this point in the procedure, the typical threshold-finding procedure was followed. The level was increased by 5 dB for each nonresponse and decreased by 10 dB for each response until threshold was recorded (responses on two ascending runs at the same level).

Following these threshold measurements, each participant was asked to not feign a loss while the entire audiogram was measured using pulsed, 200-ms tones (50% duty cycle). Threshold was also obtained for the noise stimulus (2-s duration) using an ascending approach. These measurements were used to assess the amount of the feigned loss and its configuration as well as the agreement between the noise stimulus and the average thresholds for 0.5 kHz and 1.0 kHz in persons not feigning a hearing loss. These calculations were used to assess the percentage of false positives for this noise-tone screening test for various pass-fail criteria. Similar measures were made for the other protocols.

Screening test for the spondee group: Ascending STs versus descending tonal thresholds (0.5 kHz and 1.0 kHz). Speech thresholds were measured using an ascending approach, as described in a former ASHA (1979) guideline. This procedure is more effective in identifying persons feigning a hearing loss than the one in the guideline that replaced it (ASHA, 1988; Jahner, Schlauch, & Doyle, 1994; Schlauch et al., 1996). The starting level for each speech threshold search was -10 dB HL. A forced-choice speech

threshold test was used that did not require oral responses. Participants listened to the spondees presented through an earphone while viewing a list of the nine possible words displayed on a computer monitor. The participants used a computer keyboard number pad to signal their responses to the experimenter, who recorded answers on a response sheet. The presentation level of subsequent words was set by the experimenter according to the ASHA (1979) guideline for obtaining a speech threshold using an ascending procedure. The order of word presentation was selected from a set of unique, pre-randomized nine-word lists. If more than nine words were required for a threshold measurement, another pre-randomized list was selected that did not begin with the same word that was at the end of the previous list. Next, tonal thresholds were measured using a descending approach for 0.5-kHz and 1.0-kHz tones. The initial level was 90 dB HL. The stimulus sequence for a given level was three 200-ms tones with a 50% duty cycle. The time between successive stimulus presentations was selected by the experimenter.

Following these threshold measurements, participants were instructed to not feign a loss while the ascending STs and descending thresholds for 0.5 and 1.0 kHz were repeated. The remaining audiometric frequencies and a retest of 1.0 kHz were completed using the standard procedure.

Screening test for the two-tone group: Ascending versus descending tonal thresholds (0.5 kHz and 1.0 kHz). Thresholds were measured using an ascending approach for 0.5-kHz and 1.0-kHz tones. The starting level for each threshold search was -10 dB HL. Next, threshold was measured using a descending approach for the same 0.5-kHz and 1.0-kHz tones. The starting level for these descending threshold searches was 90 dB HL. The stimulus sequence for a presentation (trial) included three 200-ms tones with a 50% duty cycle for all of these threshold searches. The time between successive stimulus presentations was selected by the experimenter.

Following these threshold measurements, participants were instructed to not feign a loss while the ascending and descending thresholds for 0.5 kHz and 1.0 kHz were obtained. Thresholds for the remaining audiometric frequencies were obtained using the standard audiometric procedure.

Screening test for the three-tone group: Ascending versus descending tonal thresholds (0.5 kHz, 1.0 kHz, and 2.0 kHz). This condition compared thresholds for three frequencies obtained using ascending and descending procedures. Thresholds were measured using a descending approach for 0.5-kHz, 1.0-kHz, and 2.0-kHz tones. Each stimulus sequence for a given level included three 200-ms tones with a 50% duty cycle. The starting level for each descending threshold search was 90 dB HL. Thresholds were measured first for 2.0 kHz followed in order by 1.0 kHz and 0.5 kHz. This was done to learn whether the last-tested frequency yields the largest threshold difference in persons feigning a loss. Harris (1958) found the smallest threshold difference for 0.5 kHz—the first frequency measured in his protocol. Next, threshold was measured using an ascending approach starting at a level of -10 dB HL for the same three frequencies using the same order of frequencies tested.

Following these threshold measurements, participants were instructed to not feign a loss while 2.0-kHz, 1.0-kHz, and 0.5-kHz retest thresholds beginning at 90 dB HL and at -10 dB HL were obtained. Thresholds for the remaining audiometric frequencies were then collected using the standard procedure.

Results

Comparisons of Thresholds When Not Feigning a Hearing Loss

When not feigning a hearing loss, participants yielded average thresholds for audiometric frequencies that were between 0 dB HL and 10 dB HL, a result consistent with those of most large survey studies of young persons (Schlauch & Carney, 2012). Reliability was excellent, as indicated by the retest threshold for a 1.0-kHz tone. None of the 120 participants in the four groups produced a retest threshold that differed by more than 10 dB from the initial one.

Of particular interest is the agreement among thresholds for the screening tests in the four protocols. Table 1 shows ascending versus descending threshold differences for each of the screening-test measures. For the noise-band and spondee groups, the mean threshold difference represents the noise-band threshold or ST minus the average threshold for 0.5 kHz and 1.0 kHz. The ST agreement includes a 4-dB correction.¹ Corrected STs were used for all comparisons between pure tones and STs, which are shown in Table 1. For the two-tone and three-tone groups, the mean threshold difference in Table 1 corresponds to the average threshold difference for ascending minus descending thresholds for 0.5 kHz and 1.0 kHz or for 0.5 kHz, 1.0 kHz, and 2.0 kHz, respectively.

All of the screening tests for participants who were not feigning a hearing loss produced average difference thresholds that agree within roughly 1 dB; however, variability was larger for the noise-band and spondee groups than it was for the tonal groups. Variability was smallest for the three-tone group.

Comparisons of Thresholds When Feigning a Hearing Loss

Most of the participants feigned moderate, flat hearing losses consistent with those reported in Schlauch et al.

¹In persons not feigning a hearing loss in the present study, STs were 4 dB lower than the average of thresholds for 0.5 kHz and 1.0 kHz in the three-tone group and in the spondee group, respectively. When the complete list of spondees is delivered in the conventional way, the Carhart (1971) PTA, which is calculated by averaging 0.5 kHz and 1.0 kHz and subtracting 2 dB from the PTA, produces near-perfect agreement with the ST (as in Schlauch et al., 1996). The small closed set of nine spondees in the present study likely yielded lower STs than when the complete list is used. Thus, a 4-dB correction rather than a 2-dB correction was made when comparing the ST and the average of thresholds for 0.5 kHz and 1.0 kHz. More specifically, all STs displayed in the present study represent “corrected” thresholds.

(1996). Average threshold data for feigned conditions for the preliminary audiogram and the follow-up screening test for all groups are shown in Table 2. Because nearly flat losses were feigned, only thresholds for 0.5 kHz, 1.0 kHz, and 2.0 kHz are shown for the preliminary audiogram. For all four groups, the initial ascending thresholds while feigning a hearing loss were at remarkably similar hearing levels—the average PTAs across groups were all within 2 dB. For the follow-up screening test, the descending PTAs were also similar across the groups and were 15 to 20 dB higher than the original ascending thresholds. The largest differences across groups were seen for ascending thresholds; the ST was 10 dB or more lower than the noise-band or tonal thresholds.

Figure 1 illustrates individual data from the screening tests for the feigned conditions. The average pure-tone thresholds (dB HL) obtained with a descending approach are shown on the abscissas. The ordinates show the ascending thresholds (dB HL) for the various stimuli. The upper panels show the noise-band (upper left) and spondee (upper right) groups, whereas the lower panels show the two-tone (lower left) and three-tone (lower right) groups. The dotted lines in each panel represent the range of expected thresholds for a particular screening test for persons not feigning a hearing loss. These ranges are based on the variability of the data summarized in Table 1 and rules for determining if a significant change in hearing occurred when assessing multiple audiometric thresholds (Schlauch & Carney, 2007). Those ranges are ± 5 dB for the three-tone screening test and ± 10 dB for the other screening tests. For the feigned hearing loss conditions, most of the data fell outside these ranges. The average discrepancy was 22.2 dB for the noise-band screening test, 30.8 dB for the spondee screening test, 19.6 dB for the two-tone screening test, and 21.5 dB for the three-tone screening test, with the ascending procedure always yielding lower thresholds irrespective of the stimulus.

Discussion

Comparison With Prior Studies

For the three-tone screening test, the presentation order of the frequencies did not matter. Harris (1958) found a 7-dB difference between the first and second and first and third frequencies tested. The three frequencies in this tonal screening test yielded nearly equal threshold differences. The differences were 20.5 dB, 22.4 dB, and 21.5 dB for 0.5 kHz, 1.0 kHz, and 2.0 kHz, respectively.

Both tonal screening tests yielded smaller differences than those reported in a previously published study of persons feigning a hearing loss. The average differences between ascending and descending thresholds of 19.6 dB for the two-tone screening test and 21.5 dB for the three-tone screening test are smaller than the difference of 26.8 dB reported by Harris (1958), who also compared thresholds for ascending and descending tones.

The spondee screening test in the present study also yielded a smaller threshold difference than the one reported by Schlauch et al. (1996) for persons feigning a loss. Schlauch

Table 1. Threshold differences (*SD* in parentheses) and the range of differences between ascending and descending threshold searches for the four test protocols for participants not feigning a hearing loss.

Variable	Noise-band group	Spondee protocol	Two-tone protocol	Three-tone protocol
Mean threshold difference (dB)	1.2 (3.6)	-0.4 (3.2)	-0.6 (1.8)	-0.4 (1.3)
Range (dB)	-5 to 7.5	-8.5 to 6.5	-2.5 to 5.0	-3.3 to 1.6

et al. (1996) found a 41.6-dB mean difference, whereas the mean difference in the present study was 30.8 dB.

Listening experience could have contributed to the smaller differences observed in the present study compared with those reported in earlier studies. In the current study, each participant had experience feigning a loss for a complete audiogram (using the standard ascending audiometric procedure) prior to administration of the screening test. This experience may have made them more consistent in feigning a loss compared with participants in the other studies, which administered the screening test at the beginning of a session.

The noise-band screening test, to our knowledge, had not been assessed before, but it was predicted to yield a larger threshold difference compared with a test based on tonal thresholds alone for persons feigning a loss. Instead, the difference was roughly equal to that for tones from the present study (see Table 2). The average noise-band screening test difference of 22.2 dB is much smaller than the 30.8-dB threshold difference found in this study for the spondee screening test among persons feigning a hearing loss.

Predictions of a Loudness Model

It was surprising that the average difference between thresholds for the noise-band screening test was not significantly larger than that for screening tests based on two tones or three tones alone. This result is inconsistent with the predictions of a loudness model that considers loudness summation. This was unexpected because a generally accepted loudness model (ANSI S3.4-2007) predicts a substantial difference between the two. The loudness model that provided the basis for this prediction is intended for sustained sounds (e.g., noise bands, complex tones, and pure tones) and is based on the work of Moore, Glasberg, and Baer (1997), whose model was used to calculate the loudness level for the stimuli used in the screening tests. Because the model is designed for sustained sounds, the loudness level of speech was calculated for its long-term average spectrum using third-octave band levels recommended in ANSI S3.5-1997. The model calculations for speech, the narrow-band noise, and 0.5- kHz and 1.0-kHz pure tones are shown in Table 3. The model output is in phons, a unit of loudness defined as the level (in dB SPL) of a 1.0-kHz tone that would be judged equal in loudness to the sound being compared.² Calculations were made for sounds presented monaurally through

²Phon values for the 1.0-kHz tone in Table 3 are not equal to its SPL because the reference condition that defines phons is based on binaural listening in the free field with the tone presented at zero degrees azimuth.

earphones. The first column of the table represents the type of stimulus. The second column is the model's predicted loudness level (in phons) for a moderate-level sound (65 dB SPL). Because audiometric thresholds are recorded in dB HL, the third column represents the reference-equivalent SPL for each of the sounds that is required to convert from dB SPL to dB HL. The fourth column of the table uses the reference-equivalent SPL to convert each of the sounds to dB HL for the 65 dB SPL presentation level. The fifth column represents the phon difference for each of the sounds at 65 dB SPL compared with that for the 1.0-kHz tone. These values were obtained by comparing phon levels for each of the sounds in the second column with the phon level for the 1.0-kHz tone. Because participants who are feigning a hearing loss are assumed to require sounds to reach a criterion loudness before they respond, the last column represents the dB HL values for each of the stimuli that would be judged to be as equally loud as the 65-dB SPL, 1.0-kHz tone. This was achieved by adjusting the dB HL values in the fourth column by the phon differences in the fifth column.

Note that in Table 3, the loudness levels (phons in Column 2) for the noise band and speech are much higher than those for the tones. Using 1.0 kHz as the reference, the phon values for the noise band and speech are 12.8 dB and 15.6 dB higher, respectively, than those for the 1.0-kHz tone for identical presentation levels (65 dB SPL). Because clinical thresholds are measured in units of dB HL, all of the SPL values were converted to dB HL before being adjusted for equal loudness (or equal phon levels). Working through an example, the corresponding dB HL values for the 65-dB SPL speech and 1.0-kHz tone are 45.5 and 57.5, respectively (see Column 4). The model predicts that for this 65-dB SPL presentation level, the phon level is 15.6 dB higher for the speech than that for the 1.0-kHz tone (Column 5). By subtracting 15.6 dB from the hearing loss value for the speech (45.5 - 15.6), a level of 29.9 dB HL is obtained, and this level is predicted to be equally loud with the 1.0-kHz tone that is 57.5 dB SPL.

Using the 1.0-kHz tone as a reference, the predicted threshold difference for someone using loudness as the basis for a feigned hearing loss is 27.6 and 15.3 dB for speech and the noise band, respectively (differences in Column 6 of Table 3). That is, the model predicts that the noise band and speech will be judged equally loud with a 1.0-kHz tone when presented at a much lower level (dB HL). This prediction is consistent qualitatively with the observed ST-PTA discrepancy reported in persons feigning a hearing loss.

Although the predicted threshold difference between the noise bands and the tones is smaller than the one predicted for speech and tones, the difference predicted by the

Table 2. Average thresholds (in dB HL) obtained from the four groups of 30 persons who feigned a hearing loss.

Protocol	Initial audiogram				Screening test		
	0.5 kHz	1.0 kHz	2.0 kHz	PTA	Ascending thresholds	Descending thresholds	Ascending–descending difference
Noise band	42.2	44.4	46.0	44.2	39.2	61.4	-22.2
Spondee	42.0	45.3	44.0	43.7	31.0	61.8	-30.8
Two tone	41.8	44.3	41.8	42.6	38.4	58.0	-19.6
Three tone	45.0	45.3	43.1	44.4	41.3	62.8	-21.5

Note. The left half of the table contains thresholds for 0.5-kHz, 1.0-kHz, and 2.0-kHz and for three-frequency pure-tone average (PTA) thresholds for the initial audiogram that was obtained prior to administration of the screening tests. The right side of the table contains thresholds from the ascending and descending threshold measurements that were part of the screening tests. The last column shows the difference between the ascending and descending thresholds searches for the screening tests.

Figure 1. Individual thresholds of the screening tests for persons who feigned a hearing loss for all four protocols. Dashed lines represent the pass–fail criterion for a positive test for functional hearing loss. NB = noise band; Freq = frequency; Asc = ascending; PTA = pure-tone average.

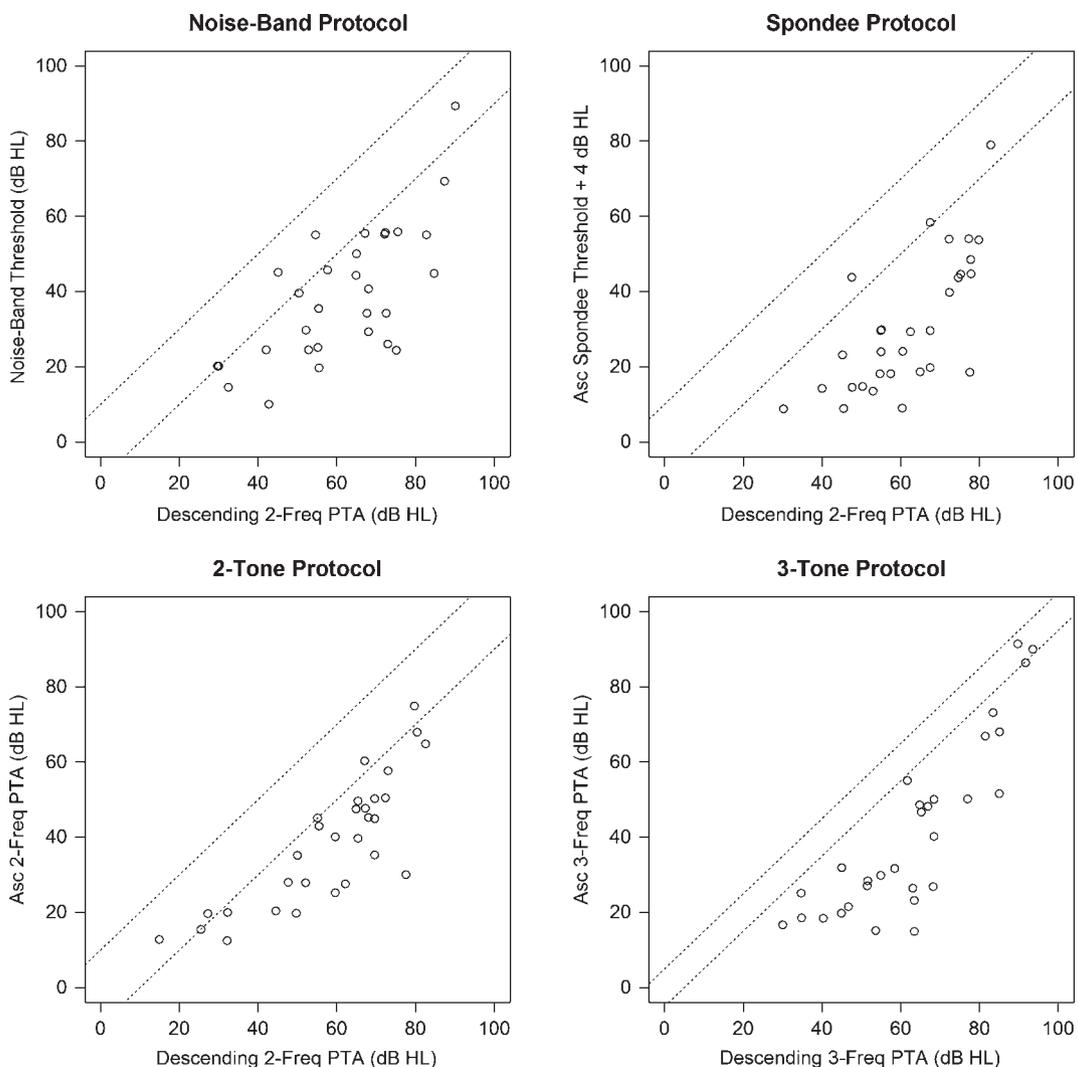


Table 3. Loudness model predictions for speech, the noise band, and 0.5-kHz and 1.0-kHz tones.

Stimulus	Predicted phons for 65 dB SPL	SPL – HL (RETSPL for TDH-39)	dB HL for 65 dB SPL (65 – RETSPL)	Phon difference at 65 dB SPL re: phons for 1.0 kHz	dB HL adjusted for equal loudness with 1.0-kHz tone
Speech	68.2	19.5	45.5	15.6	29.9
Noise	65.4	10.0	55.0	12.8	42.2
0.5-kHz tone	51.3	11.5	53.5	–1.3	54.8
1.0-kHz tone	52.6	7.5	57.5	Reference	57.5

Note. The last column displays the predicted levels (dB HL) for each of the stimuli when they are adjusted to be equally loud with a 57.5-dB HL, 1000-Hz tone. SPL = sound pressure level; HL = hearing loss; RETSPL = reference equivalent SPL; TDH-39 = earphones (Telephonics).

loudness model is still substantial (15.3 dB) for persons feigning a loss who are using a loudness reference. It is unknown why the predictions did not hold, but a psychoacoustic study of the loudness of noise bands of various widths found a negligible loudness difference for bandwidths between 200 and 800 Hz (Verhey & Kollmeier, 2002). By contrast, Verhey and Kollmeier (2002) found that a 6400-Hz-wide noise yielded the equivalent of a roughly 15-dB loudness difference compared with a 200-Hz-wide noise band; 200 Hz is about the width of a midfrequency pure tone in the auditory system at 1.0 kHz. Although a bandwidth of 6400 Hz would produce the desired loudness effect (the expected difference between a tone and the noise band), it is not a viable choice for a screening test for functional hearing loss. Some persons who feign a loss exaggerate an existing loss, and if the existing loss has a sloping configuration, the wideband noise would not produce the desired loudness summation if it were inaudible in some frequency regions. Also, measured thresholds for persons who are not feigning a loss would be determined by the frequency region with the most sensitive thresholds. This would complicate the interpretation of a screening test based on a limited sample of pure-tone thresholds obtained from two or three frequencies.

Explanation for the Large ST–PTA Discrepancy in Persons Feigning a Loss

Ascending thresholds for speech produce larger discrepancies between thresholds obtained using descending tones than do ascending thresholds for tones or for a band-pass noise. The 8.5-dB larger discrepancy for the average ST–PTA difference (dB) compared with that for the average noise–PTA threshold difference is not consistent with loudness summation, as noted in the phon differences in Column 2 of Table 3. Instead, the difference is likely a result of the difference between detection threshold and recognition threshold reference levels for audiometric zero for speech. In other words, the detection threshold for the noise stimulus in a group of individuals with hearing thresholds within normal limits was 10 dB SPL. A nearly identical level would have likely been obtained for a speech detection threshold. A 9-dB higher level is required for a spondee recognition threshold than for a threshold for detection or awareness of spondees (Chaiklin, 1959). Persons presenting with functional hearing loss, who likely base their judgments on loudness, would not take into

account the level difference required for recognition. This would result in speech producing a larger discrepancy than band-pass noise in persons presenting with functional hearing loss. Whereas some authors attribute the ST–PTA discrepancy to a difference in loudness for broadband stimuli compared with narrow stimuli (Martin, 2009; Schlauch et al., 1996), Ventry (1976) speculated that calibration accounts for the difference.³ The 8.6-dB to 9.3-dB larger threshold discrepancy (see last column of Table 2) for persons feigning a hearing loss for the spondee screening test than for the screening tests based on pure tones or a noise band supports Ventry’s (1976) speculation.

Clinical Application: Development of a Protocol

The data in Figure 1 illustrate that all of the screening tests were effective in identifying persons feigning a hearing loss, but none were perfect. As Figure 1 shows, a few persons who feigned a hearing loss for each screening test fell inside the range of expected threshold differences for persons who were not feigning a loss.

These screening tests can be used in isolation with the expectation that a few persons who are feigning a loss will be missed (calculated by 1.0 minus the true-positive rate), but a consideration of all of the audiometric threshold data—the initial audiogram, the test–retest threshold at 1000 Hz, and the screening test—will likely yield superior results. These superior results are possible because a participant’s outcome on all of the threshold measures was not perfectly correlated. That is, a participant who is feigning a loss can be negative for functional hearing loss for the three-tone screening test but positive for functional hearing loss by producing a large test–retest threshold for 1000 Hz for the initial audiogram.

Below is an analysis that supports combining threshold measures in a clinical protocol for identification of functional hearing loss. The protocol was developed by analyzing the test outcomes for each threshold measure for each

³Martin’s (2009) hypothesis for the ST–PTA discrepancy in persons with functional hearing loss is not based on loudness summation per se but rather the more rapid growth of loudness for low-frequency sounds than for midfrequency sounds. The low-frequency spectral components in speech would dominate the loudness percept and cause it to be louder than a 0.5-kHz or 1.0-kHz tone at the same presentation level.

participant in the feigned hearing loss condition and the nonfeigned condition and combining them in a manner that produced the best performance.

One of the measures obtained from each participant was a retest of 1.0 kHz for the initial audiogram. Previous studies (Shepherd, 1965; Ventry & Chaiklin, 1965) found that persons feigning a hearing loss are very good at producing consistent retest thresholds at 1.0 kHz, and our results agree with those findings. Table 4, which shows test–retest thresholds for 1.0 kHz for all of the participants, shows that all persons not feigning a loss yielded retest thresholds that agreed within 10 dB. Although 89% of persons who were feigning a hearing loss also yielded agreement within 10 dB, 11% produced larger differences. Ventry and Chaiklin (1965) reported an identical finding. Of their participants, 11% presenting with functional hearing loss exceeded 10 dB on a single retest of 1.0 kHz. Thus, a discrepancy of 15 dB or more on a retest for a 1.0-kHz tone is a useful pass–fail criterion for functional hearing loss. Although the true-positive rate is low for this measurement, the following analysis demonstrates this test’s usefulness in confirming a diagnosis of functional hearing loss within the context of a protocol.

A second measure that can be made is a comparison of the average thresholds for tones obtained in the initial audiogram with the same thresholds for frequencies obtained in the screening test for descending tones. A pass–fail criterion of a difference greater than 5 dB yielded a true-positive rate of 73.33% (22 of 30 participants) for identification of functional hearing loss for this single comparison of average descending thresholds from the three-tone screening test with the average ascending thresholds from the preliminary audiogram for the same three frequencies. Three persons who were not identified as presenting with functional hearing loss using the three-tone screening test were correctly identified by comparing the PTA for descending tones with the initial audiogram.

On the basis of the data from the most effective screening tests, two multistep protocols for identifying functional hearing loss were developed. The spondee protocol and three-tone protocol produced the highest true-positive rates and lowest false-positive rates for identifying functional

Table 4. Test–retest for 1.0 kHz for the initial audiogram for 120 participants feigning a hearing loss and for the same participants while not feigning a loss.

Pass–fail criterion (±)	True positives (%)	False positives (%)
≥5 dB	74	35
≥10 dB	34	4
≥15 dB	9	0
≥20 dB	2	0

Note. True positives represent the percentage of persons feigning a loss who had a threshold on retest that was equal to or greater than the pass–fail criterion. False positives correspond to the percentage of persons cooperating with the test who produced a retest threshold that was equal to or greater than the pass–fail criterion.

hearing loss. Described below are the multistep protocols that produced the most accurate identification of functional hearing loss. A positive finding on any single measure is consistent with functional hearing loss.

Spondee Protocol Multistep Assessment (100% True-Positive Rate; 0% False-Positive Rate)

Procedure. Measure the entire audiogram, including a retest of the threshold for 1.0 kHz. Next, administer the spondee screening test, a comparison of ascending ST and descending thresholds at two frequencies (0.5 kHz and 1.0 kHz) with three pulses at each level consisting of 200 ms on-time and 200 ms off-time. The time between successive stimuli as level changes is varied.

Evaluation. The evaluation consisted of the following steps:

1. Compare 1.0 kHz test–retest on the original audiogram (pass–fail criterion of ≥15 dB discrepancy).
2. Compare ascending speech thresholds and average tonal thresholds for 0.5 and 1.0 kHz from the spondee screening test (pass–fail criterion of >10 dB discrepancy for speech; 90% true-positive rate, 0% false-positive rate).
3. Compare average tonal thresholds (0.5 and 1.0 kHz) from original audiogram with the ones from the descending approach (pass–fail criterion of ≥10 dB difference).

Three-Tone Protocol Multistep Assessment (100% True-Positive Rate; 0% False-Positive Rate)

Procedure. Measure the entire audiogram, including a retest of the threshold for 1.0 kHz. Next, administer the three-tone screening test, a comparison of ascending and descending thresholds at three frequencies (0.5 kHz, 1.0 kHz, and 2.0 kHz) with three pulses at each level consisting of 200 ms on-time and 200 ms off-time. The time between successive stimuli as the level changes is varied.

Evaluation. The evaluation consisted of the following steps:

1. Compare 1.0 kHz test–retest from the original audiogram (pass–fail criterion of ≥15 dB discrepancy).
2. Compare average tonal thresholds for 0.5 kHz, 1.0 kHz, and 2.0 kHz for ascending and descending approaches from the three-tone screening test (pass–fail criterion of >5 dB difference; 90% true-positive rate, 0% false-positive rate).
3. Compare average tonal thresholds (0.5 kHz, 1.0 kHz, and 2.0 kHz) from original audiogram with the ones from the descending approach in the three-tone screening test (pass–fail criterion of >5 dB discrepancy).

The results of the multistep assessments obtained using the spondee screening test and the three-tone screening test are shown in Tables 5 and 6. The initial test–retest of 1.0 kHz is included in these protocols even though no positive cases were identified by this test alone. A much larger sample

Table 5. Diagnostic accuracy of a multistep protocol for identifying functional hearing loss for the group that received the three-tone screening test.

Combination	Components of the protocol			Persons identified with functional hearing loss (<i>n</i>)	
	Three-tone screening test	Retest of 1.0 kHz	Descending PTA and initial audiogram	True positives (30 or 100%)	False positives (0 or 0%)
1	+	+	+	1	0
2	+	–	–	8	0
3	–	+	–	0	0
4	–	–	+	1	0
5	+	+	–	0	0
6	+	–	+	18	0
7	–	+	+	2	0
8	–	–	–	0	0

Note. The results are shown for all possible combinations of positive results (+) and negative results (–) for the pass–fail criteria for the three tests in the protocol. Numbers represent the number of persons (out of 30) who were identified by different combinations of the protocol’s tests. True positives were obtained from tests when the participants were feigning a loss. False positives represent participants’ results when they were not feigning a loss. PTA = pure-tone average.

would be required to know for certain whether the retest of 1.0 kHz contributed uniquely to the identification of functional hearing loss. Given that numerous studies have shown that differences of 15 dB or more for the retest of 1.0 kHz represent unreliable audiometry and that this measurement is made as a routine check of reliability, we believe this supports the use of this measure as part of the protocol.

Also consider that the false-positive rates in Tables 5 and 6 for “descending PTA and initial audiogram” are predicted and not measured. The possible importance of the initial audiogram for persons not feigning a loss was not anticipated when the study began, so pure-tone thresholds for the screening test were collected to represent thresholds for the nonfeigned conditions for screening-test frequencies. The standard deviations of PTA threshold differences for the nonfeigned conditions for the two-frequency and three-frequency screening tests were 1.3 and 1.8 dB, respectively. These standard deviations are so small that the 5-dB pass–fail criterion for the three-tone comparison with the initial

audiogram and the 10-dB pass–fail criterion for the two-tone comparison with the initial audiogram would not likely be exceeded in persons not feigning a hearing loss.

An inspection of Tables 5 and 6 shows that the three-tone and spondee screening tests were equally effective; both tests yielded 100% true-positive rates and 0% false-positive rates when considered in a multistep process that used data from the initial audiogram. Given that the tests are equally effective in this study, are there any advantages of one over the other? One consideration is that the tonal test is not affected by a sloping hearing loss configuration in the way that the one based on ST–PTA agreement would be. For the tonal screening test, the threshold comparisons are at the same single frequency, so hearing loss configuration is not a factor. Another consideration is the equipment required to implement the tests. The tonal test requires only an audiometer. An automated spondee screening test requires a monitor to display the words and custom programming. Even if a manual spondee test is administered,

Table 6. Diagnostic accuracy of a multistep protocol for identifying functional hearing loss for the group that received the spondee screening test.

Combination	Components of the protocol			Persons identified with functional hearing loss (<i>n</i>)	
	Spondee screening test	Retest of 1.0 kHz	Descending PTA and initial audiogram	True positives (30 or 100%)	False positives (0 or 0%)
1	+	+	+	2	0
2	+	–	–	2	0
3	–	+	–	0	0
4	–	–	+	3	0
5	+	+	–	0	0
6	+	–	+	23	0
7	–	+	+	0	0
8	–	–	–	0	0

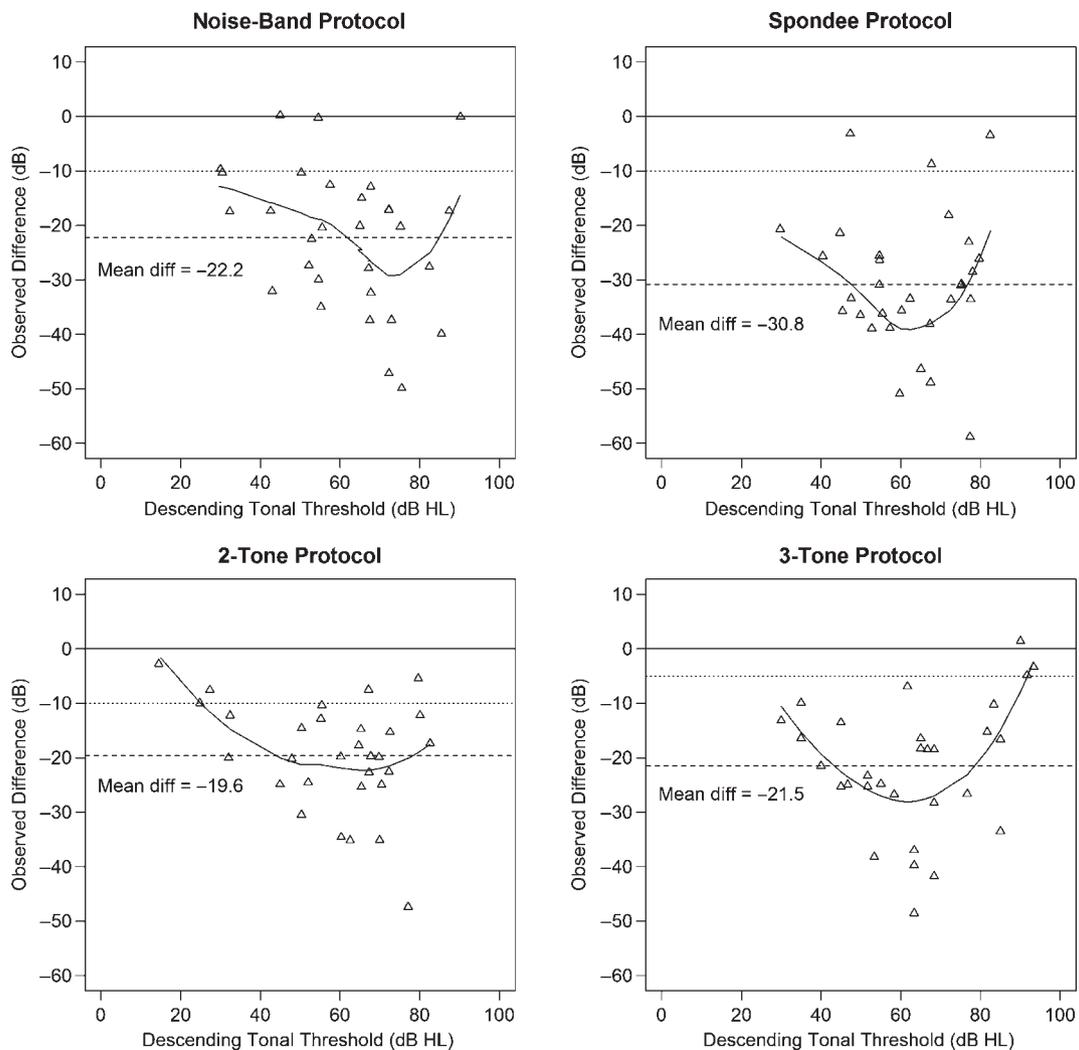
Note. The results are shown for all possible combinations of positive results (+) and negative results (–) for the pass–fail criteria for the three tests in the protocol. Numbers represent the number of persons (out of 30) who were identified by different combinations of the protocol’s tests. True positives were obtained from tests when the participants were feigning a loss. False positives represent participants’ results when they were not feigning a loss. PTA = pure-tone average.

a more complex audiometer with speech stimuli capability is required; the tonal test can be administered using the most basic audiometer. Another issue is the time required to administer both tests. We did not keep a record of the test times, but Jahner et al. (1994) found that instructions for ST testing were completed in an average of 36 s (without familiarization with the list), and the test administration itself required in an average of 1 min 45 s when done manually. The pure-tone screening test needs no further instruction, and the threshold search takes approximately 2 min for all three frequencies.

The screening tests assessed in isolation are imperfect. Some persons were able to beat the best two screening tests in this study. There was a trend for persons feigning losses at the extremes of the dynamic range to yield smaller discrepancies on threshold screening tests. According to a model

of loudness perception (Braida et al., 1984), listeners use the extremes in their dynamic range (threshold and the loudness discomfort level) as anchors for making judgments. These anchors provide a reference for making judgments of sensation magnitude, and more precision is expected when a sound level produces a sensation close to one of these reference points. In other words, if someone fakes a nearly profound loss, their loudness judgments for various audiometric threshold tasks will be more consistent than if they had faked a moderate loss. The same is true of persons who feign mild losses. There is evidence in the current study that supports the idea that listeners are better at maintaining a loudness reference for extreme levels. The U shape of the fitted data in Figure 2 demonstrates this trend in all four groups. That is, the discrepancy noted on the screening tests tended to be smaller when a very large or small amount of

Figure 2. The discrepancies between the ascending and descending thresholds for each of the screening tests. The abscissas illustrate the ascending tonal thresholds in dB HL. The ordinates represent the difference, in dB, between the ascending and descending thresholds. Solid lines at 0 dB represent perfect threshold agreement. Dotted lines at -5 dB or -10 dB represent the pass-fail criterion for functional hearing loss for a particular screening test. Dashed lines at a negative decibel value indicate the mean discrepancy. Solid lines in each panel represent a locally weighted scatterplot smoothing fit to each data set.



loss was feigned. For the severe to nearly profound losses, audiologists have other tools (i.e., auditory brainstem-evoked responses, acoustic reflexes, and otoacoustic emissions) that are helpful for diagnosis of functional hearing loss. The otoacoustic-emissions and acoustic-reflex testing can be implemented in hearing conservation programs administered by technicians if insert earphones are used. Mild feigned losses are not a problem if the exaggerated thresholds fall within the normal range.

All persons who were feigning a loss and who were missed by the spondee screening test and the three-tone screening test were identified by making comparisons between the descending tonal thresholds from the screening test and those from the preliminary audiogram. In other words, making multiple, repeated threshold measurements improved diagnostic effectiveness. This outcome is consistent with Ventry and Chaiklin's (1965) study, which found that multiple retests of 1.0 kHz improved the effectiveness of that measure for identifying functional hearing loss. A single retest identified 11%; four retests identified 66%. In the present study, the retests compared average thresholds for multiple frequencies from the initial audiogram with those of the screening test, and an improvement in the true-positive rate was noted. Although conducting multiple tests can increase the false-positive rate of a test battery, the pass-fail criteria in the present study represent such a large discrepancy that an increase in false-positive diagnoses should be minimal.

Conclusions

In this study, we reached the following conclusions:

1. Ascending–descending threshold procedures are highly effective for identifying functional hearing loss.
2. Noise bands are not an effective substitute for STs in a protocol for identifying functional hearing loss.
3. When the original audiogram was taken into account, the spondee screening test and the three-tone screening test produced 100% true-positive rates for identification of functional hearing loss.

Acknowledgments

This research was supported in part by Office of Naval Research Work Unit Number WU50904 through the Naval Submarine Medical Research Laboratory. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the U.S. Department of the Navy, U.S. Department of Defense, or U.S. Government. The third author, Lynne Marshall, is an employee of the U.S. Government. This work was prepared as part of her official duties. Title 17 U.S.C. §105 provides that "copyright protection under this title is not available for any work of the United States Government." Title 17 U.S.C. §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person's official duties.

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Appendix

Instructions for Feigning a Hearing Loss

In this study, you will fake a hearing loss on several hearing tests. Many people attempt to do this during real hearing tests to receive payment after an accident or for workers' compensation. It is important for professionals in different fields to understand how people fake a hearing loss during hearing tests. Your participation in this study will contribute to our understanding of how people fake hearing losses.

Do your best to put yourself in the position of someone who is attempting to fake a hearing loss because he/she hopes to convince a company or government agency that he/she should be compensated a large sum of money. In other words, you are engaging in fraudulent behavior because you believe that the payoff is worth the risk you are taking. For example, pretend that you are coming into our clinic to get a hearing evaluation to support a case in legal proceedings in an insurance claim against a private company or government agency.

The methods you use for pretending and the amount of hearing loss you choose to imitate are entirely up to you. You should start pretending that you are a person faking a hearing loss as soon as I tell you to begin and continue until I tell you the testing is completed.

As an incentive for you to succeed in faking a hearing loss, a \$25.00 reward will be given to the participant who does the best job of faking. There will be 30 participants, and each person will be given the same instructions and the same tests. The reward will be given after all participants have been tested.

I will give you instructions on when to start and when to stop pretending. Please do not stop pretending until I tell you to stop. Remember that your success is financially important to you! If you have any questions, please ask them now.
