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Early detection of non-organic hearing loss using a simple tone-in-noise test

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Abstract

Early detection of non-organic hearing loss (NOHL) is important in order to ensure appropriate management decisions. One possible audiometric test for achieving this is the tone-in-noise (TIN) test although its current format is not widely applicable and may not optimize accuracy. We sought to investigate a modified TIN test, using narrowband noise, and the influence of different noise levels and alternative approaches to determining the outcome. Seventy-five normal-hearing and 8 hearing-impaired subjects were asked to feign or exaggerate a hearing loss. The shift in genuine or exaggerated/feigned thresholds with the introduction of ipsilateral noise was determined. The TIN test was able to accurately separate between genuine and feigned thresholds when using narrowband noise presented at the effective masking level corresponding to the apparent tone threshold and using a 'fail' criterion of a repeatable threshold shift of ≥ 10 dB at one or more frequencies. It also produced similar shifts in exaggerated thresholds. In conclusion, this modified TIN test is a potentially accurate method to rapidly identify unilateral and bilateral NOHL in a wide range on contexts and could be applied to automated audiometry.

Keywords: *Audiology, hearing, non-organic, test*

Introduction

Non-organic hearing loss (NOHL) continues to present a challenge to hearing assessment services. While estimated to occur in approximately 2% of clinical audiology cases, its prevalence is thought to be considerably higher in medicolegal and military contexts, and its early detection is of clear importance.[1,2] However, early identification is often difficult, especially in busy services or where available equipment is limited. Also, the reliability of audiometric thresholds in NOHL can be similar to that expected from genuine hearing thresholds.[3] There is a need for simple and accurate techniques, applicable to a range of contexts, to augment conventional audiometry for the early identification of NOHL and to focus further specialist, definitive testing (albeit less widely available and more expensive), such as evoked responses, on those individuals at high risk. Although many techniques have been suggested,[4] cases continue to be reported of individuals with undetected NOHL receiving inappropriate amplification, medical, or surgery.[5-7] This suggests that existing techniques are not or cannot be implemented effectively. Another limitation of many of existing techniques is difficulty implementing them in automated hearing testing commonly used in hearing surveillance and military contexts. One exception is the little-known tone-in-noise (TIN) test.[8]

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The TIN test originates from the Doerfler-Stewart Test,[9,10] but does not require the specialized stimuli (spondees and saw-tooth noise), equipment, and procedures. The TIN test simply involves comparison of pure-tone hearing thresholds for a given ear and frequency in quiet and in ipsilateral 'masking' noise, and could be applied to manual and automated audiometry. The rationale is that the noise, if sufficiently intense, will interfere (e.g. through partial masking[11]) with a subject's judgment when using a strategy for feigning/exaggerating the hearing loss based on the loudness of the tone; such a strategy seems common.[3,12] In an initial investigation of the TIN test, Pang-Ching[8] set the level of *broadband* masking noise according to an individual's hearing threshold level (HTL) in quiet (the highest level possible without, theoretically, influencing the hearing thresholds if genuine given knowledge of the masking effectiveness of the noise). Using manual audiometry, Pang-Ching found that HTLs were higher (poorer) in this noise by approximately

15 dB in 10 normal-hearing subjects asked to feign a hearing loss and by approximately 25 dB in 3 patients considered, on the basis of other tests, to have NOHL. This compares to a mean shift of 5 dB in 7 patients with a genuine hearing loss. While the TIN test looks promising, appropriately calibrated broadband noise is not widely available and it is unclear if the level of noise and other parameters of the test protocol are optimal (for example, the lack of a check of repeatability of the results). The aim of the present study was to investigate the TIN test using (i) the *narrowband* noise that is available and calibrated on most standard audiometers, making the test more widely applicable and minimizing the loudness and annoyance of the noise; and (ii) alternative but practical test parameters. This was implemented using manual audiometry initially with a view to extending to automated testing if found to be effective. Given the challenges of recruiting subjects with actual NOHL for such a study, 3 experiments were conducted using over 80 subjects asked to feign or exaggerate a hearing loss. The rationale is that it is *necessary* (albeit not sufficient) for the TIN test to be able to accurately identify this form of NOHL if its deployment in services is to be considered.

Methods

Approval of the Institute of Sound and Vibration Research Human Experimentation Safety and Ethics Committee was obtained before commencing these experiments. Subjects, aged 18–60 years, were recruited from the student/staff population of the University of Southampton. Otologically normal (ON) subjects had audiometric thresholds of 15 dB HL or better, from 250 to 8000 Hz in octave intervals. Stimuli were pure-tones and narrow bands of noise produced by a calibrated Type 1 audiometer,[13] presented to one ear of a subject via an ER-5A insert earphone and foam tip. The level of the noise will be referred as 'noise level' (NL): At 0 dB NL, the noise was presented at the effective masking level[14] corresponding to the subject's apparent HTL in quiet. Up to 4 noise levels were used: 0, -5, -10, and -15 dB. Hearing threshold levels (HTLs) were estimated using standard manual audiometry[15] that was modified in two ways to guard against subjects guessing the level of the tone: (i) the starting level varied quasi-randomly over a range of approximately 30 dB in 5-dB steps; (ii) a 'null trial' was occasionally used at the level of the tone on the previous trial (i.e. tone presented; response ignored).

Fourteen ON subjects participated in Experiment 1. Feigned HTLs in quiet (HTL_Q) and then in noise (HTL_N) at 1 kHz were estimated using the modified audiometry. In this experiment only, subjects were presented with a reference tone at 45 and 60 dB sensation level and were instructed to use this to feign their hearing loss. Values for pairs of HTL_Q and HTL_N were accepted only if HTL_Q was within ± 5 dB of the reference level. Four pairs of HTL_Q and HTL_N were obtained with each noise and reference level. Thirty new ON subjects participated in Experiment 2, of which 17 were audiology students. Subjects were instructed to feign a hearing loss of whatever magnitude, and using whatever strategy, they wished but to do so as reliably as they could. Three pairs of estimates of HTL_Q and HTL_N were then obtained at 1 kHz and each of the 4 noise levels using the modified PTA procedure. Thirty-one new ON subjects participated in Experiment 3, of which 15 were audiology students. This was identical to Experiment 2, except that data were collected at both 1 kHz (n = 31) and 4 kHz (n = 30), at only the 3 highest noise levels, with a single estimate of HTL_Q and with genuine as well as feigned HTLs. Data from 8 subjects with known sensorineural hearing loss (SNHL) were also collected (i.e. with genuine and exaggerated thresholds) at a low (0.5 or 1 kHz) and/or high-frequency (4 kHz). In all experiments, the orders of testing at the noise levels and frequencies were counterbalanced across subjects.

Results

The mean (and standard deviation, SD) of feigned HTL_Q for Experiments 2 and 3 were 55 dB HL (13 dB) and 52 dB (17 dB), similar to previous reports.[16] Figure 1a plots the threshold shifts from Experiment 1 (1 kHz only; error bars represent 1 SD for one illustrative condition) in comparison to theoretical predictions (see Discussion). The mean HTL_N was higher than the mean HTL_Q in all conditions (t-tests: $P < 0.001$), and the mean threshold shift increased with noise level for both reference levels (Pearson's $r > 0.99$ and $P \leq 0.002$ in both cases). Figure 1b plots the equivalent results with ON subjects from Experiment 2 (feigned HTLs and 1 kHz only) and Experiment 3. As with Experiment 1, the mean feigned HTL_N was statistically significantly higher than the mean feigned HTL_Q in all conditions (except 4 kHz with –10 dB NL) and in both experiments (t-tests: $P \leq 0.005$). The effect of noise level on feigned HTLs overall was very similar for Experiment 1 and 2; the effect was similar at 0 dB NL Experiment 3 and less at the lower levels. Statistically significant shifts were also apparent with genuine thresholds with –5 and 0 dB NL only (t-tests: $P \leq 0.009$). An ANOVA showed that the mean threshold shifts were smaller with genuine than with the feigned thresholds ($F_{1,29} = 95$; $P < 0.001$), that the mean threshold shift increased with noise level ($F_{2,58} = 81$; $P < 0.001$), and that the latter depended more strongly on noise level in the feigned condition ($F_{2,58} = 20$; $P < 0.001$). There was at best a weak trend in Experiments 2 and 3 for the threshold shifts to be weaker in subjects with higher feigned HTL_Q. Similar shifts were also obtained in those with and without audiology knowledge and with the SNHL subjects, the latter shown in Figure 2. It is apparent that the threshold shifts in most SNHL subjects increase with noise level in both genuine and feigned conditions and are greater in the feigned conditions. The feigned threshold shifts at 0 dB NL in the SNHL subjects are generally close to a practically detectable amount (10 dB).

Figures 3a and b present results from Experiment 3 in terms of the proportion of subjects that ‘failed’ the TIN test given two definitions; 95% confidence intervals[17] (CIs) are plotted in two illustrative cases. The results from Experiment 2 were similar at the highest noise level. With *Approach (a)*, an individual ‘fails’ the test if the threshold shift from the first pair of HTL_Q and HTL_N is ≥ 10 dB.[8] With *Approach (b),* an individual ‘fails’ if the threshold shift between the first HTL_Q and 2 or 3 HTL_N is ≥ 10 dB, thus requiring some repeatability. For each approach, alternative ways of combining information across multiple frequencies are compared. Other plausible approaches were investigated, but none performed better overall than *Approach (b).* In fact, there is little discernable difference between *Approaches (a)* and *(b)* in Figure 3, particularly in the context of the CIs. However, *Approach (a)* has poor test-retest agreement when the overall proportion was between approximately 20 and 80%. For further comparison, no more than 5% and 30% failed based on unreliable genuine or feigned thresholds in quiet, respectively, defined as a range of 3 HTL_Q greater than 5 dB. The TIN test clearly performs best at 0 dB NL; performance at this level also seems best when ‘failing’ a subject if the threshold shift is ≥ 10 dB at one or both of two frequencies. The results from the 8 SNHL subjects confirm that the TIN test is probably of little value at –10 and –5 dB NL. Overall, these results demonstrate that the TIN test can distinguish well between genuine and feigned hearing loss and has potential for distinguishing between genuine and exaggerated hearing loss.

Discussion

The average feigned threshold shift in noise at 0 dB NL is similar in all 3 experiments, at 1 kHz and 4 kHz and whether subjects were provided with a reference tone (Experiment 1) or were free to use any strategy they chose (Experiment 2 and 3); it also does not appear to be strongly dependent on existing SNHL or on the degree of audiological naivety. It is also similar to that found by Pang-Ching;[8] the noise in that study corresponding approximately to 0 dB NL. Results were less consistent between Experiments 2 and 3 at the lower noise levels, suggesting that these are less appropriate for use in a test; the reason for this inconsistency at the lower levels is not clear. Overall, the trends are also comparable to theoretical predictions using a loudness model,[11] especially when accounting for a difference in step sizes (0.5 dB in prediction vs. 5 dB in experiments) and that subjects were likely to respond only if the loudness of the tone *exceeded* their anchor.

One might expect the genuine threshold shifts in the ON subjects to be zero on average given the effective masking noise levels used here. However, the small shifts we observed in Experiment 3, particularly at 0 dB NL, are plausible given the required accuracy of the calibration of the stimuli, inter-subject variation in the effect of the noise, and other issues related to calibration. Shifts were also observed at the higher noise level with some subjects with hearing loss. In addition to the explanations suggested above, it is known that some individuals with sensorineural loss are also more susceptible than ON subjects to the effects of noise under conditions, similar to those occurring during Experiment 3.[18]

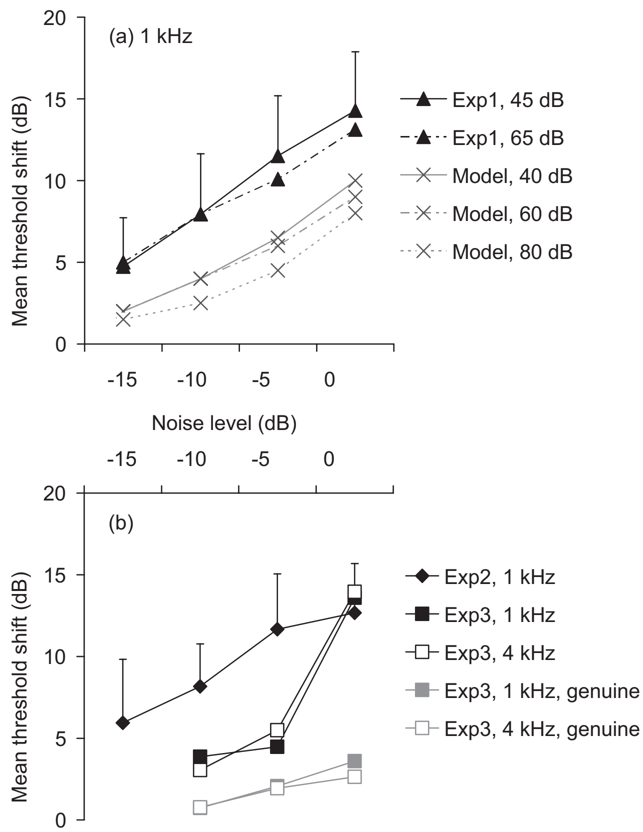

Figure 1: Effect of noise, at several levels, on feigned hearing thresholds (and, for Experiment 3, genuine thresholds) from 3 experiments with ON subjects; errors bars show ± 1 SD for illustrative conditions. Model predictions for 1 kHz are also shown in panel (A) these are based on the model of partial loudness by Moore *et al*. (1997), using finer resolution (0.5-dB step) than in the experiments (5-dB steps)

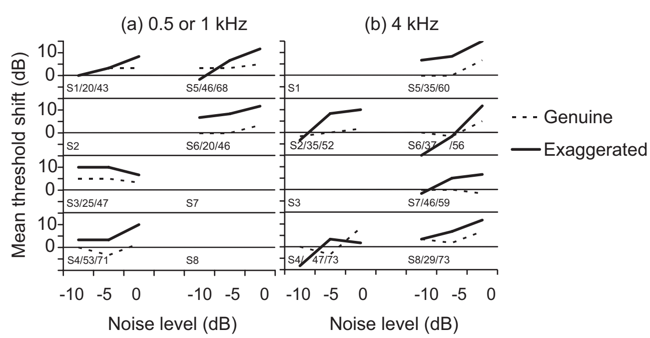

Figure 2: Effect of noise, at several levels, on genuine and exaggerated hearing thresholds for 8 hearing-impaired subjects presented separately

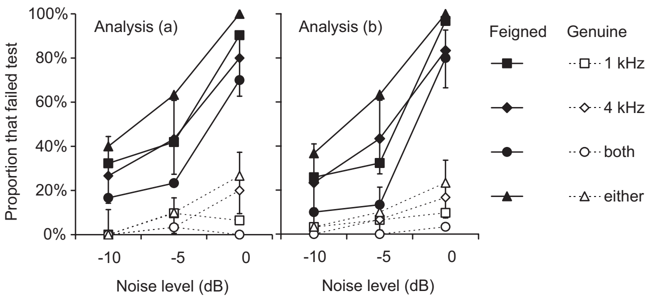

Figure 3: Proportion of ON subjects, when thresholds were either genuine or feigned, that were categorized as feigning a hearing loss (i.e. 'failing' the TIN test) at several noise levels and with various approaches to the test (see text); errors bars show 95% CIs for illustrative conditions

In summary, we suggest that using ipsilateral narrowband noise at 0 dB NL and defining a positive shift as *at least 2 out of 3 thresholds in noise are higher than one threshold in quiet by 10 dB or more* (observed at one or more frequencies) is practical and potentially effective. It has advantages compared the original suggestion in (i) using a masker that is widely available and easy to calibrate, and (ii) requiring an element of repeatability. Note also that the TIN test has the advantage over the Stenger test[19] in being applicable to bilaterally symmetrical thresholds.

There are several important limitations with the current study. The findings here need to be confirmed in a larger sample of subjects with sensorineural hearing loss (although the results with ON subjects should generalize to conductive hearing loss) and ages (e.g. more diverse strategies for NOHL). The former is important because, as mentioned above, genuine thresholds might be affected by the noise more than expected from ON subjects.[18] Loudness recruitment might also have an influence, although it should reduce both the threshold shift *and* the magnitude of the exaggerated component, potentially making the latter less clinically important anyway. The operating characteristics of TIN test should be investigated and compared to alternative tests (e.g.[20]); our informal comparisons suggest the TIN test might be at least quicker out than some alternatives. While the TIN test cannot be used to estimate the genuine threshold, this is unlikely to be a significant disadvantage as it is advisable, following any subjective test, to confirm the results using objective threshold tests (e.g. evoked responses); our initial estimates of the performance of the modified TIN test suggest that it could be effective in identifying those most likely to warrant such further testing. Consequently, estimation of its performance in automated audiometry also seems warranted.

Finally, the findings of this and Pang-Ching's study are also relevant to the interpretation of other tests involving ipsilateral noise that are not intended to identify NOHL but might be sensitive to it nonetheless. One example is the threshold-equalizing noise (TEN) test for 'dead regions.'[21] A 'dead region' refers to damaged or absent function of a group of inner hair cells, or corresponding neurons, previously tuned to a particular frequency region. These are not always apparent on the audiogram because inner hair cells adjacent to the dead region may be stimulated sufficiently to enable tone detection, referred to as 'off-frequency' listening, and at levels lower than one might intuit. The cochlear processes involved in off-frequency listening have also been predicted to produce loudness recruitment under some conditions, mimicking a loss of outer hair cells.[22] One clinical test to identify dead regions is the TEN test, which works by masking the off-frequency portions of the cochlea that might be enabling off-frequency listening using specially constructed broadband noise. (The principle of this is the same as masking the non-test *ear* during conventional audiometry; off-frequency listening presents a form of cross-hearing, though across the cochlea rather than the head.) While the principle of that test is fundamentally different to the TIN test for NOHL, they are similar in practice: The effect of supra-threshold noise on tone thresholds is estimated using similar criteria to those suggested here. A person with NOHL would, therefore, be expected to be positive for a dead region on the TEN test. Consequently, NOHL should be considered when interpreting the results of the TEN test and any other tests that are similar in practice. In contrast, the TIN test with one-third-octave noise, as recommended here, is expected to be effectively insensitive to dead regions because of the narrower bandwidth. One possible strategy if a tester is suspicious that a positive TEN for cochlear dead regions is actually due to NOHL is to also conduct the TIN test (without requiring reinstruction): If the subject is positive on both tests, NOHL is more likely (though not certain); if the subject is negative on the TIN test, a dead region is more likely (though again not certain, e.g. because some people with sensorineural loss are more sensitive to the effects of noise, as noted above).

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