A noise tolerance tracking test to evaluate noise reduction

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INTRODUCTION

Listening in background noise has long been a concern for hearing aid users. A noise reduction algorithm is one way to address hearing aid users' concerns in background noise. Different methods to evaluate the effectiveness of noise reduction algorithms have been used. One such method is the Acceptable Noise Level (ANL) test [Nabelek et al (1991); Rogers et al (2003)]. The ANL test measures the level of noise the listener can tolerate while listening to speech at MCL. This method does not reveal the stabilization time of a noise reduction algorithm. Knowing about the time required to stabilize fully is important, because noise reduction systems vary in their stabilization times. For example, noise reduction in the Widex DREAM hearing aid requires at least 20 seconds to stabilize, while the Widex UNIQUE hearing aid requires less than 5 seconds to stabilize. Considering the differences in stabilization times, one may be interested in developing a test that can reveal such differences in perceived noise tolerance between algorithms. This test should present noise and allow the listener to adjust the noise level to reach a level where they can "just put up with" the noise. The duration of the test should be long enough to reveal a stable result, but not too long where the listener fatigues. The test should also track the noise, sampling the adjusted noise level each second, so that information about the changes in loudness perception are available over time. This tracking method can potentially show differences in hearing aid processing (i.e. noise reduction) over time.

Figure 1 illustrates a hypothetical noise tracking test. During the first half of the test, the hearing aid feature (i.e. noise reduction) is deactivated. When the test begins, the listener hears fixed-level speech and increases the noise level to a level where they can "just put up with" it. The time it takes to reach that level is T1 and the stable noise level is L1. Halfway through the test, the noise reduction feature is activated. Theoretically, the listener may tolerate more noise with the feature activated, so the listener increases the noise level over time (T2) to reach a new stable level (L2).

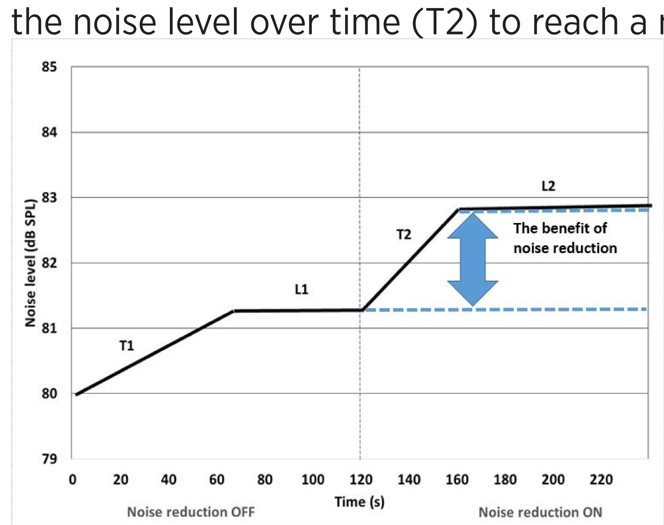

Figure 1: Hypothetical noise tracking result. Ideally, the listener increases the noise level over time (T1) until they can no longer tolerate the noise. Once that level is reached, that noise level is maintained as long as it is tolerable (L1). If the hearing aid processing is changed in the middle of the test, the listener may react to this change and increase the noise level over time (T2) until a new tolerable noise level is reached (L2).

The noise tracking test introduced for this study presents speech at a fixed level. Since speakers are expected to raise their vocal efforts in a noisy background depending on the level of the background noise, it is reasonable to expect that they will be speaking at a loud speech level and not at MCL. Pearsons et al (1977) showed that such vocal effort could result in speech levels ranging from 71 dB to 89 dB SPL. Consequently, it may be worthwhile to fix the speech level at 85 dB SPL to reflect the higher speech levels encountered in loud noisy backgrounds. The noise is continuous and tracked by the listener, allowing the listener control of the noise level until the listener is no longer willing to tolerate or put up with the noise without becoming tense or tired while following the words of the story. This procedure reveals the stabilization time for the noise reduction algorithm. The noise tracking test runs over a fixed duration, where the first half of the test evaluates no-noise reduction and the second half evaluates noise reduction. The listener establishes a tolerable noise level for each half. The difference between the two tolerable noise levels represents the benefit of noise reduction.

One objective of this study was to determine the test-retest reliability of the noise tracking test. Both within-session and between-session reliability was desired. An additional objective was to demonstrate that the noise tracking test could report listeners' noise tolerance over time with changing hearing aid processing.

METHODS

Subjects

Thirteen hearing-impaired participants (9 females and 4 males) were included in the study. Their average age was 65.31 years (SD = 16.83 years; range 31-82 years). Nine participants had prior hearing aid experience using a RIC style hearing aid, while three participants used custom hearing aids. One participant who did not use any hearing aids had participated in hearing aid research studies at our facility. The average hearing aid experience was 12.15 years (SD = 12.82 years).

Hearing instruments

Each subject was fitted binaurally with a Widex UNIQUE 440-FS hearing aid and then a Widex DREAM 440-FS hearing aid using appropriate strength receiver and instant-fit tips. Coupler output for the UNIQUE and DREAM hearing aids was matched to ensure similar output. The following settings were used: Noise reduction: variable (off/on); Microphone: omnidirectional; Feedback cancellation: SuperGain. All other features were deactivated.

Stimuli

Passages from the Connected Speech Test (CST, Cox et al, 1987) were used as stimuli. CST passages were edited to remove long pauses between sentences to create a more continuous monologue. The passages were compiled to form new lists of sentences each list lasting 2 minutes. These sentences were presented from a loud-speaker placed directly in front at 0° azimuth at a fixed level of 85 dB SPL. A continuous speech-shaped noise available from the Hearing In Noise Test (HINT, Nilsson et al, 1994) was used as the background noise. Noise was presented from 90°, 180°, and 270° azimuth and its level was adjusted by the participant to meet the highest tolerable noise level. The starting noise level was fixed at 80 dB SPL (i.e., 5 dB SNR). The noise was presented simultaneously with the speech (i.e., 2 min duration).

Procedures

We determined the tolerable noise level in the sound field at a fixed speech level of 85 dB SPL. To ensure that listeners did not tolerate more noise at the sacrifice of speech understanding, we also estimated the speech intelligibility scores for the CST at the stabilized noise levels when noise reduction was "Off" and "On." A new CST passage was presented with speech at 85 dB SPL and noise at subject's tolerable noise level. The number of words correctly repeated from the lists of sentences was recorded. Listeners who could not correctly identify at least 80% of the target words would be reinstructed and the noise tolerance re-measured. This ensured that the noise tolerance level was achieved with reasonably good speech understanding, and that a higher noise level (with NR activated) did not sacrifice speech understanding.

Subjects completed the noise tracking test once during the first visit. Nine of the thirteen subjects returned three months later for the second visit. The noise tracking test was completed twice during the second visit. Thirty minutes separated the two trials during which time subjects were engaged in a separate listening task.

Instructions

"You will hear some noise in the background while you listen to the female talker. I want you to turn the noise level up as high as you can so you are no longer willing to tolerate or put up with the noise without becoming tense or tired while following the words of the story. You should bracket around that sound level to make sure that level is reached. Once you are at that level, I want you to monitor that noise level so it is at the same loudness at all times. That is, if it appears softer than before, you should turn the volume up; if it is louder than before, you should turn the volume down to keep at the same level. The level of the noise should not affect your understanding of the speech passage. If so, you should lower the loudness of the noise so speech becomes understandable again. We will prompt you periodically to remind you to keep that noise level constant."

RESULTS

The mean noise tolerance measured during session 1 was similar (< 1 dB) to the mean noise tolerance measured during the first trial in session 2, averaged across both the omnidirectional (omni) and omnidirectional plus noise reduction (omni + NR) conditions (Table 1, 1 vs O). The mean noise tolerance measured during trial 2 in the second session was higher than that measured during the first trial. This suggests some learning effect when the same test was presented within the same session. Averaged across the omni and the omni + NR condition, the intra-session 95% confidence interval was calculated to be **2.07 dB**. Within session 95% CI was 2.57 dB for the omni condition and 1.57 dB for the omni + NR condition. The mean 95% CI measured between sessions for both hearing aid conditions was **4.18 dB**, with a range from 3.36 dB to 5.62 dB.

Table 1: Mean, standard error, range, and 95% confidence intervals for the difference in noise tolerance measured in session 1 (O) and the two trials (1 and 2) during the second session for the Omnidirectional and Omnidirectional + Noise Reduction conditions. n=9.

		Mean	SE	Range	Lower	Upper	95% CI
Omni	1 vs 2	-2.89	0.65	(-6,0)	-4.17	-1.61	2.57
	1,2 vs O	0.44	1.24	(-6,7)	-1.99	2.88	4.86
	1 vs O	-1.00	1.43	(-8,7)	-3.81	1.81	5.62
	2 vs O	1.89	1.11	(-4,7)	-0.29	4.07	4.36
Omni + NR	1 vs 2	-1.22	0.40	(-3,0)	-2.01	-0.44	1.57
	1,2 vs O	-0.17	0.86	(-5,4.5)	-1.85	1.51	3.36
	1 vs O	-0.78	0.86	(-5,4)	-2.47	0.91	3.38
	2 vs 0	0.44	0.90	(-5,5)	-1.32	2.21	3.53

Figure 2 tracks the averaged noise tolerance for the UNIQUE and DREAM hearing aids. The first 2 minutes was measured without noise reduction and the last 2 minutes with noise reduction. During the first two minutes (no NR), no difference in the mean noise tolerance was observed. Both hearing aids tracked at about 84 dB. Upon activation of the noise reduction, both hearing aids provided approximately **3 dB** of additional noise tolerance (87 dB overall). At the end of the test,the final noise tolerance was again similar between the UNIQUE and the DREAM. The difference between the two aids was the time required to achieve the stable noise level upon activation of noise reduction. The UNIQUE stabilized within **25 seconds** after NR activation, while the DREAM required nearly **50 seconds** to stabilize.

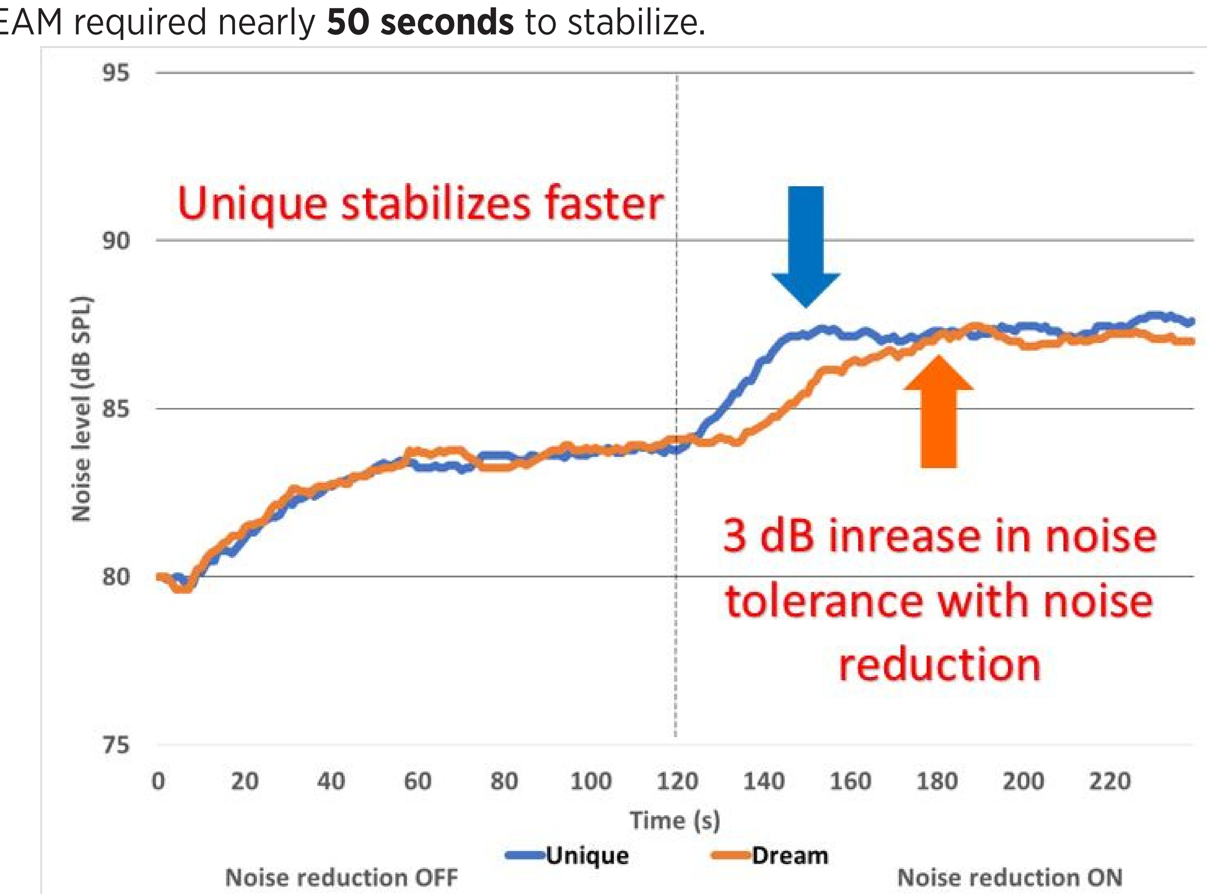

Figure 2. Averaged tracking curve for UNIQUE (blue) and DREAM (orange) hearing aids (n=13). Noise reduction is turned off for the first half of the test and then activated at 120 seconds. All other features are off. The UNIQUE hearing aid reaches the stable tolerable noise level before the DREAM hearing aid.

CONCLUSIONS

The current study demonstrated that the noise tracking test is a reliable and repeatable test. Aided hearing impaired listeners were tested with varying hearing aid conditions, yielding 95% confidence intervals of 2.07 dB within session and 4.18 dB between - sessions. Since the noise tracking test demonstrated strong test-retest reliability, the test may be used to evaluate how different hearing aid features affect noise tolerance. Indeed in the current study, results revealed that noise reduction can provide approximately 3 dB of additional noise tolerance compared to without noise reduction. Furthermore, the noise tracking test revealed differences in noise reduction stabilization time between two hearing aids. One potential benefit of increased noise tolerance may be an improvement in perceived listening comfort. If a listener can tolerate greater noise levels, listening may be less effortful in typical noisy environments.

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