Agreement Between Subjective and Objective Measures of Noise Benefits

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INTRODUCTION

One of the main complaints of hearing aid wearers is the inability to hear speech in noise (Kochkin, 2002). Thus, it is not surprising that various strategies of noise management have been utilized from directional microphones to noise reduction algorithms in today's digital instruments. Directional microphones have been shown to improve signal to noise ratios (SNR); however, the improvement was not correlated with hearing aid acceptance (Bentler et al, 1993; Humes et al, 1996). Noise reduction algorithms had not been shown to improve SNR; however, it has been demonstrated that it improved listening comfort.

In 1991, Nabelek et al. introduced a different measure, the Acceptable Noise Level (ANL) to predict hearing aid acceptance. This measure determined the listener's most comfortable listening level (MCL) in quiet and the background noise level (BNL) at which s/he is willing to tolerate while listening to speech at MCL. The difference between the MCL and BNL was termed the Acceptable Noise Level or ANL. Hearing aid wearers with a lower ANL (accepting higher noise level) had a higher acceptance rate for amplification; whereas, those with a higher ANL (accepting lower noise level) tended to be less satisfied with amplification. If this is indeed true, this index may be used to measure the real-world efficacy of various hearing aid features (e.g., directional microphone) instead of the typical laboratory/clinical measures of speech in noise tests such as the SPIN, HINT, or the QuickSIN tests. Another advantage of using this index is its efficiency and the ease of implementation. It would be ideal if the benefit shown with the ANL measure is also seen in other objective measures of performance.

On the other hand, it is well recognized that objective performance may not correlate with subjective performance. While one may be accepting of a hearing aid, it is possible that the same hearing aid may not show any improvement in objective measures. To evaluate the extent that one may apply the ANL measure, Freyaldenhoven et al (2005, 2006) measured the subjective and objective benefits provided by directional microphones and reported that the two measures yielded similar improvement. This suggests that these measures may be used interchangeably. Because of the limited research that examined the generalizability of the correlation between subjective and objective measures of benefit in other hearing aid features, we decided to include this metric in our evaluation of the Inteo hearing aid so that we can:

1. Determine the objective SNR improvement (on the HINT) provided by the high-definition Locator microphone, speech enhancer, and classic noise reduction algorithms on the Inteo;
2. Determine the subjective SNR improvement (by the ANL method) provided by the high-definition Locator microphone, speech enhancer, and classic noise reduction algorithms on the Inteo
3. Determine the correlation between subjective and objective measures of benefits provided by each of the three hearing aid features.

DESCRIPTION of KEY INTEO FEATURES

The Widex Inteo hearing aid is the first digital hearing aid that utilizes Integrated Signal Processing (ISP) to achieve its desired functions. The readers are referred to Kuk (2006 – ISP supplement ref) for a detailed description of the various features. This section will cover a brief review of the key features that were examined in this report.

1. ***High definition Locator*** – The Inteo uses a 15-channel, fully adaptive dual-microphone system that can switch its polar pattern in each of its 15 channels from an omni directional mode to a bi-directional mode and any polar patterns in between. In addition, it has a speech preservation mechanism that maintains the omni directional mode when speech is presented.
2. ***Classic noise reduction*** – The Inteo uses a 15-channel noise reduction algorithm that uses a patented "level-distribution function" analysis to differentiate between speech and noise inputs. Once noise is identified, gain in the specific channel is reduced depending on the input level, signal-to-noise ratio measured in that channel, as well as the importance of that channel to overall speech intelligibility.
3. ***Speech enhancer*** - The Speech Enhancer is another "noise reduction" algorithm that calculates the Speech Intelligibility Index (SII, ANSI-1997) of any noisy environment and adjusts its settings so that the SII is maximized without reaching discomfort. The goal is not only to improve comfort in noise but also to provide the best possible speech intelligibility for the patient while considering the input (speech spectrum **and** noise spectrum) and the wearers' hearing loss.

A key difference between the classic noise reduction algorithm and the speech enhancer is the sensitivity of the SE to the hearing loss of the wearer. With classic noise reduction algorithms, the amount of gain reduction is simply a function of the input. Typically, for the same input, the same amount of gain reduction will be seen regardless of the patient's hearing loss. With the SE, there will be extra audibility due to the consideration of the patient's hearing loss (see Figures 1a and 1b).

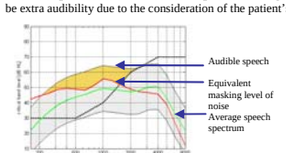

Figure 1a: Uniform gain reduction with classic NR

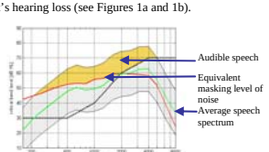

Figure 1b: Extra audibility with SE in high frequencies

METHOD

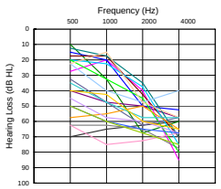

Figure 2: Average right and left ear audiogram for each subject

Subjects

Twenty adults with symmetrical bilateral sensorineural hearing loss participated in the study.

- There were 14 males and 6 females.
- All configurations of hearing loss were included (see Figure 2).
- Seven of the subjects had not worn hearing aids previously.
- Their ages ranged from 44 to 89 with a mean age of 70 years.
- All participants were native English speakers.

Hearing Aid Test Conditions

The subjects were evaluated under five hearing aid test conditions:
1. omni microphone with no noise reduction "Omni only"
2. omni microphone with classic noise reduction "Omni + NR"
3. omni microphone with SII based noise reduction "Omni + SII"
4. adaptive directional microphone with no noise reduction "Dir only"
5. adaptive directional microphone with SII based noise reduction "Dir + SII"

Evaluation Criteria

Objective measure of speech in noise performance – The HINT (Hearing In Noise Test) was modified so that the speech-shaped noise is continuous and its level was fixed at 75 dB SPL-C. The level of the speech signal was adjusted in 4 dB step for the first 4 sentences and 2 dB for the 5th to 20th sentences. The speech stimulus was presented from the front loudspeaker at 0° azimuth, while the noise stimulus was delivered from three loudspeakers at 90°, 180°, and 270°, each one meter from the subject.

Subjective measure of speech in noise performance - The ANL (Acceptable Noise Level) metric was used. The speech stimuli were CST (Connected Sentence Test) passages presented in a paired format to determine the MCL for the passage in quiet. A 2 dB step size was used. The background noise level (BNL) was determined using the HINT speech-shaped noise as the competition. The initial noise level was played at MCL. A bracketing approach was used to adaptively change the level until the listener reported that they could no longer accept the noise and follow the story. The final BNL was calculated as the average of the last four levels heard by the listener. ANL was calculated as MCL minus BNL. Like the HINT condition, the speech stimulus was presented from the front loudspeaker at 0° azimuth, while the noise stimulus was presented from 90°, 180°, and 270°.

RESULTS

Objective performance – HINT performance

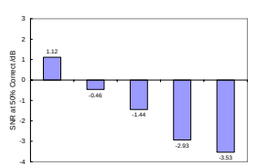

Figure 3a: Absolute HINT scores (dB)

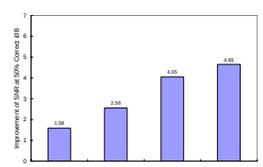

Figure 3b: HINT benefit compared to "Omni only"

The average absolute HINT scores (dB) is seen in Figure 3a.

- The results for the "Omni +SII" were approximately 1 dB better than "Omni +NR" and 2.5 dB better than "Omni only".
- The results with the "Dir only" (no noise reduction) were 1.5 dB better than the "Omni +SII" and 2.5 dB better than the "Omni +NR".
- The results with the "Dir +SII" were 0.5 dB than "Dir only"; approximately 2 dB better than "Omni +SII" and 3 dB better than "Omni +NR".

The difference in HINT results between the "Omni only" and other hearing aid settings was the benefit obtained with those settings as seen in Figure 3b.

- Greatest benefit when compared to "Omni only" was obtained with "Dir +SII" (4.65 dB).
- Benefit on the HINT with "Dir only" was 4.05 dB. This was 0.6 dB poorer than "Dir +SII" but approximately 1.5 dB better than "Omni +SII".
- Benefit on the HINT with "Omni +SII" was 2.56 dB. This is approximately 1 dB more benefit with the speech enhancer than seen with the classic noise reduction.
- Benefit on the HINT with "Omni +NR" was 1.58 dB.

RESULTS (cont.)

Subjective Performance – ANL

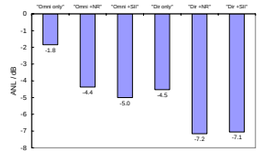

Figure 4a: Absolute ANL scores (dB)

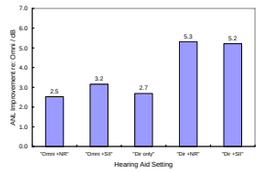

Figure 4b: ANL benefit compared to "Omni only"

The average absolute scores on the ANL test with all subjects averaged together are shown in Figure 4a. A negative number suggests that the background noise level was higher than the speech MCL.

- There was no difference in ANL scores for directional microphones and with either noise reduction algorithm.
- There was approximately 2.5 dB improvement with the noise reduction algorithms over "Dir only".
- There was approximately a 0.5 dB improvement in ANL score with "Omni +SII" over "Omni +NR".
- Compared to an "Omni only", the "Omni +NR" and "Omni +SII" had improved ANL scores by 2.5 dB to 3 dB respectively.
- Similar ANL performance was seen between "Omni +NR" and "Dir only".

The difference in ANL results between the "Omni only" and other hearing aid settings was the benefit obtained with those settings as seen in Figure 4b.

- When compared to "Omni only", higher ANL improvement (benefit) was seen with "Omni +SII" (3.2 dB) than "Omni +NR" (2.5 dB).
- Similar ANL benefit was also seen between the "Dir only" (2.7 dB) and "Omni +NR" (2.5 dB). However, it is LOWER than the benefit of the "Omni + SII" condition.
- Similar ANL benefit was also seen between "Dir +NR" (5.3 dB) and "Dir +SII" (5.2 dB). These results are approximately 2 to 2.5 dB better than "Dir only" or "Omni +NR"

Correlation between subjective and objective noise benefit

Figures 5a- 5d show the correlation between the ***Benefit Scores*** (re: omni only condition) as measured by the HINT and the ANL for four hearing aid conditions: "Omni +NR"; "Omni +SII"; "Dir only"; and "Dir +SII".

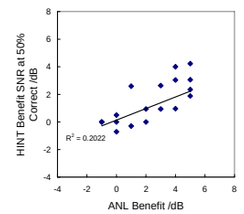

Figure 5a: HINT benefit vs. ANL benefit with "Omni +NR"

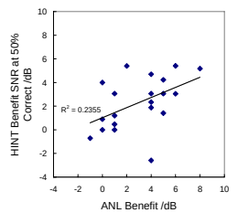

Figure 5b: HINT benefit vs. ANL benefit with "Omni+SII"

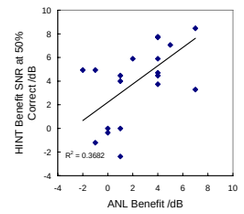

Figure 5c: HINT benefit vs. ANL benefit with "Dir only"

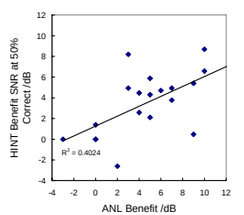

Figure 5d: HINT benefit vs. ANL benefit with "Dir +SII"

RESULTS (cont.)

When the benefit scores of the ANL and HINT were compared, significance was seen in all hearing aid test conditions:

- The correlation between ANL benefit and HINT benefit scores with "Omni +NR" was $R^2 = 0.20$. This is statistically significant ($p < 0.05$, see Figure 5a).
- The correlation between ANL benefit and HINT benefit scores with "Omni +SII" was $R^2 = 0.24$. This is statistically significant ($p<0.03$, see Figure 5b).
- The correlation between ANL benefit and HINT benefit scores with "Dir only" was $R^2 = 0.37$. This is statistically significant ($p<0.005$, see Figure 5c).
- The correlation between ANL benefit and HINT benefit scores with "Dir +SII" was $R^2 = 0.40$. This is statistically significant ($p<0.003$, see Figure 5d).

Table 1: Correlations between absolute HINT and ANL scores

	ANL_Omni NROff	ANL_OmniNR	ANL_OmniSII	ANL_LocNROff	ANL_LocSII
HINT_OmniNROff	r=0.378	r=0.063	r=0.010	r=0.058	r=-0.090
	p=0.122	p=0.803	p=0.968	p=0.820	p=0.724
HINT_OmniNROn	r=0.042	r=-0.183	r=-0.134	r=-0.182	r=-0.261
	p=0.870	p=0.468	P=0.597	p=0.470	p=0.296
HINT_OmniSII	r=-0.014	r=-0.158	r=-0.122	r=-0.103	r=-0.101
	p=0.955	p=0.531	p=0.628	p=0.684	p=0.690
HINT_LocNROff	r=-0.122	r=0.116	r=0.291	r=0.237	r=0.421
	p=0.629	p=0.647	p=0.241	p=0.343	p=0.082
HINT_LocSII	r=-0.240	r=-0.224	r=-0.014	r=-0.014	r=0.073
	p=0.338	p=0.373	p=0.956	p=0.955	p=0.775

Table 1 shows the correlation coefficients between the absolute HINT score and the absolute ANL scores for each of the hearing aid conditions. As one can see, none of the hearing aid conditions showed a significant correlation between the two performance measures.

CONCLUSIONS

This study showed that that the classic noise reduction algorithm, the speech enhancer algorithm, and the fully adaptive multichannel directional microphone all resulted in a significant improvement in signal-to-noise ratio when their performance was compared to that of the omni directional microphone alone condition. Such an improvement was seen both subjectively (ANL measure) and objectively (on the HINT). The significant correlation between the benefits seen on the HINT and ANL indicates a strong agreement between both measures. This agreement may indicate that when a patient shows benefit on a speech in noise test (e.g., HINT), his/her subjective acceptance of amplification may improve as well. Both measures may be used to measure hearing aid benefits offered by these new features.

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