Laboratory evaluation of directional preference: Effect of background noise location and stimulus type

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The aim of this study was to investigate the influence of background noise location and stimulus type as factors contributing to the discrepancy in directional preference between the laboratory and real-world. The task used for this purpose was very similar to that employed with patients – indicating a subjective preference in a paired-comparison format. The main findings were: (1) directionality is preferred when the signal is located at 0° azimuth, (2) asymmetrical directional setting is not undesirable in an asymmetrical noise field, and (3) there is no significant difference in subjective microphone preference in a simulated real-world environment.

MOTIVATION

Over the past decade or so, directional benefit has been unequivocally demonstrated to improve speech understanding in background noise in the laboratory (e.g., Hornsby and Ricketts, 2007; Ricketts and Mueller, 2000). However, real-world directional advantage can be best described as lukewarm. Studies have shown that hearing aid users preferred directionality only about 25% of the time in their everyday lives (Cord *et al*., 2002; Walden *et al*., 2004). Further, success with directional microphones in everyday living cannot be reliably predicted from laboratory measures of directional advantage (Cord *et al*., 2004). While surveys of hearing aid users indicate that 38% are dissatisfied with, and 95% desire improvement in, the performance of hearing aids in noisy situations (Kochkin, 2002b), the prevalence of directional microphones in the marketplace is only about 25% (Kochkin, 2005). Nonetheless, the good news is that hearing aid users do report a directional advantage in several environments (Kochkin, 2002b).

The disconnect between laboratory and real-world findings is typically attributed to the acoustics of the environment. This includes: (1) the presence, location and distance of signal and noise (Walden *et al*., 2004), (2) reverberation (Leeuw and Dreschler, 1991; Ricketts, 2000), and (3) typical input levels (Banerjee, 2008; Wagener *et al*., 2008). The aim of this study was to investigate the influence of background noise location and stimulus type as factors contributing to the discrepancy in directional preference between the laboratory and real-world.

METHODS

Participants and hearing aids

Twenty adults with mild-to-moderate sensorineural hearing loss (Fig. 1, left panel)

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participated in the study (24 individuals were recruited of whom 3 were unable to finish due to personal reasons and one of whom was dismissed due to an inability to perform the paired comparison task). Participants who completed the study consisted of 9 females and 11 males with an average age of 70 years (range: 55-83 years). All individuals were experienced hearing aid users.

Participants were fitted bilaterally with Starkey's Destiny 1600 BTEs and skeleton earmolds with a 2 mm select-a-vent. The hearing aid gains were matched to eSTAT, Starkey's proprietary fitting formula. The expansion and feedback cancellation algorithms were turned on at their default settings – expansion ratio of 0.4 and adaptive, respectively; noise management was turned off. The devices were programmed with 2 memories that were identical except for the microphone mode – one was set to omnidirectional and the other to directional. The *in situ* directivity of the devices was verified at the start of the study by comparing the directional response for a signal located at 0° azimuth to that at the null. Based on the criterion that the response at the null should be attenuated at least 8 dB between 500 and 3000 Hz relative to the response at 0° azimuth, the *in situ* directivity was found to be adequate (Fig. 1 – right panel). [It should be noted that this is a clinical measurement that does not optimize the null for individual frequencies.]

Study participants were divided into 2 groups based on the type of stimuli used to evaluate directional preference. One group (n=11) listened to standard laboratory stimuli, while the other group (n=9) listened to simulated real-world stimuli. The 2 groups were treated in exactly the same way in all other respects.

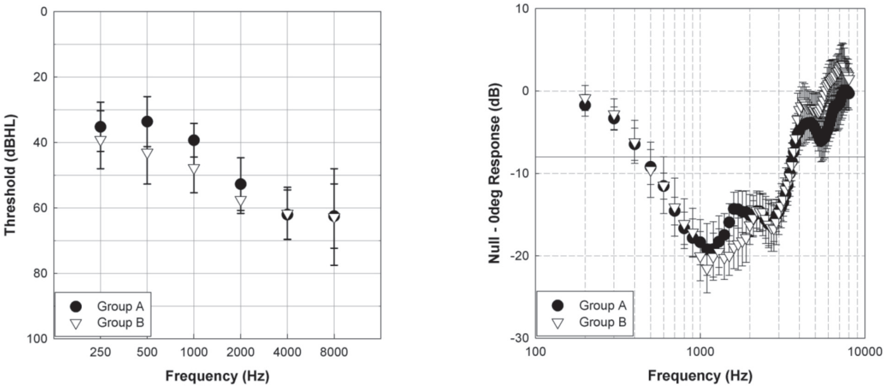

Fig. 1: Average (symbols) and 95% confidence intervals (error bars) of the pure tone thresholds (left panel) and *in situ* directivity (right panel) for the 2 groups of participants.

Procedure

Two outcome measures were used for this study. The Performance-Perceptual Test (PPT), described by Saunders and Cienkowski (2002) assesses the measured and perceived ability to understand speech. Specifically, performance and perceptual speech reception thresholds in noise (SRTNs) are obtained in separate runs using the adaptive protocol described by the Hearing in Noise Test (Nilsson *et al*., 1994) protocol. In this study, the PPT was used to evaluate directional advantage objectively and subjectively with comparable tasks. Thus, performance and perceptual SRTNs were obtained in the omnidirectional and directional modes. The background was 7 channels of uncorrelated speech-shaped noise located symmetrically between 45° and 315° azimuth presented at an overall level of 65 dBA. The speech, sentences spoken by a single male talker, was varied adaptively in level and presented via a loudspeaker located at 0° azimuth. For the performance SRTN, the participant's task was to repeat as much of the sentence as possible and the tester scored the response as correct or incorrect. On the other hand, for the perceptual task, the participant decided for him-/herself whether or not the sentence was understood and indicated as such by tapping the appropriate button on a touch screen.

Directional benefit in daily life is often assessed on the basis of the patient's response to, "Which program did you prefer?" In keeping with this theme, the second outcome measure used was subjective preference for the omnidirectional or directional microphone mode using a paired comparison format. Thus, the left-right combinations evaluated were O-O, D-O, O-D and D-D. The pair of settings evaluated on any given trial was randomized. The participants' task was to select the setting preferred for speech understanding via a touch screen. As mentioned previously, study participants were divided into 2 groups depending on whether they listened to standard laboratory stimuli (Group A, Fig. 2) or simulated real-world stimuli (Group B, Fig. 3). In general, the speech was always located at 0° azimuth, while the noise was either diffuse (S0ND and restaurant) or to the left of the listener (S0NL, theatre). The real-world stimuli, selected to have a sound field configuration similar to the standard stimuli, were judged to be realistic by three listeners with normal hearing.

In order to evaluate the feasibility of the subjective preference task, 10 participants were involved in a pilot phase prior to the start of the study. The stimuli and sound field configuration were similar to the S0ND condition. During this phase, performance and perceptual SRTNs were obtained in the omnidirectional and directional modes. Further, participants were asked to indicate a subjective preference for the omnidirectional or directional microphone mode. Only symmetrical microphone modes were evaluated in this phase – i.e., omnidirectional or directional in both ears.

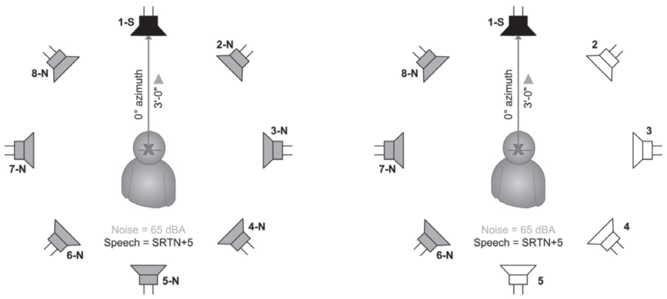

Fig. 2: Sound field setups for S0ND (left panel) and S0NL (right panel) – standard stimuli. Speech-shaped noise delivered via grey speakers at an overall level of 65 dBA. Speech presented via black speaker at 5 dB above omnidirectional performance SRTN.

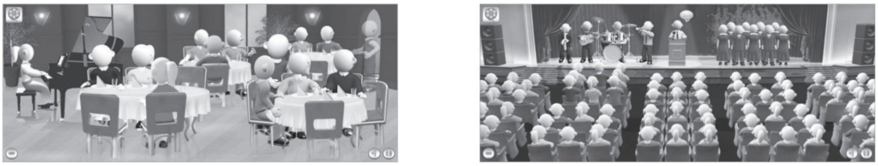

Fig. 3: Sound field setups for restaurant (left panel) and theater (right panel) – simulated real-world stimuli delivered via a 5.1 surround sound system. *Restaurant*: Background noise of other people talking and dishes presented at 65 dBA; speech consisting of two male talkers across the table presented at -2 dBSNR. *Theater*: Background noise of applause and music on the left presented at 70 dBA; speech consisting of a male talker at the podium presented at -4 dBSNR.

RESULTS

Pilot

Figure 4 shows the outcome of the pilot testing. The key results can be summarized as follows:

1) The hearing aids provided significant ($p<0.05$) directional advantage for speech understanding in noise,

2) There is no significant ($p>0.05$) difference between objectively measured (i.e. performance) and subjectively perceived directional advantage,

3) The directional mode is preferred 5 times more often than omnidirectional, and

4) Subjective preference for directionality varies only minimally as a function of SNR.

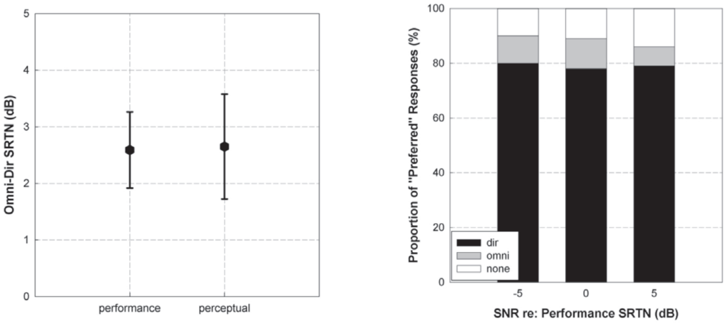

Fig. 4: Measured and perceived directional advantage (left panel) and subjective preference for omnidirectional or directional microphone mode or neither (right panel). Symbols and error bars represent the mean and 95% confidence interval, respectively.

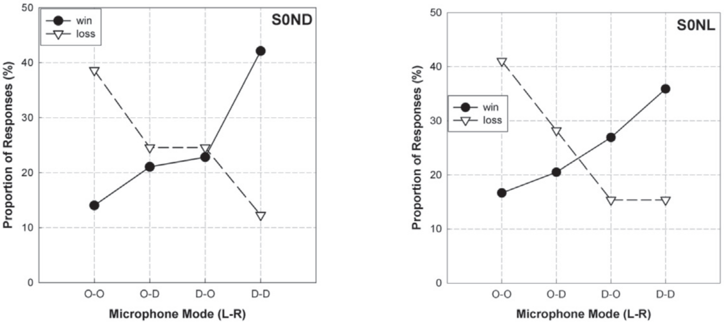

Fig. 5: Percentage of wins and losses for the various microphone settings in the S0ND (left panel) and S0NL (right panel) conditions.

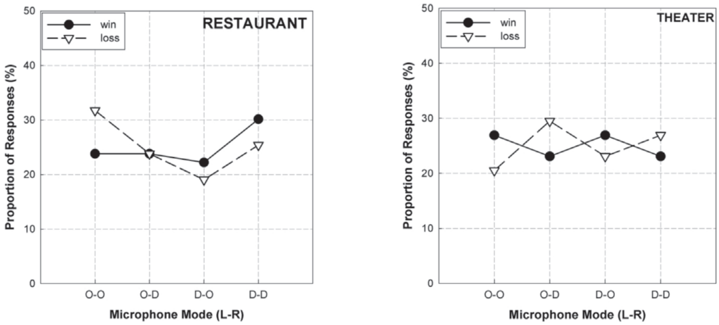

Fig. 6: Percentage of wins and losses for the various microphone settings in the restaurant (left panel) and theater (right panel) conditions.

Qualitative analysis

The data were qualitatively analyzed in terms of the percentage of wins and losses. These observations can be summarized as follows:

1) S0ND (Fig. 5 – left panel): There were substantially more losses than wins for the symmetrical omnidirectional (O-O) setting, while the opposite was true for the symmetrical directional (D-D) setting.
2) S0NL (Fig. 5 – right panel): There were more losses than wins for the settings with omnidirectional in the left ear (O-O and O-D), while the opposite was true for settings with directional in the left ear (D-O and D-D).
3) Restaurant (Fig. 6 – left panel): The symmetrical omnidirectional (O-O) setting was the only one with more losses than wins, although the number of wins and losses were comparable across the various settings.
4) Theater (Fig. 6 – right panel): The symmetrical omnidirectional (O-O) setting had the fewest losses in this condition, although the number of wins and losses were comparable across the various settings.

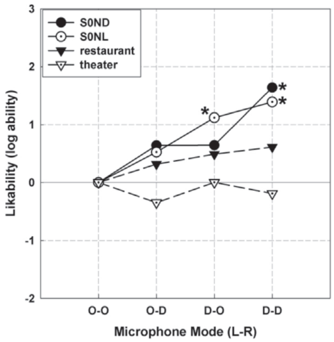

Fig. 7: Relative log ability coefficients for all 4 conditions. The log abilities are described in reference to the bilateral omnidirectional (O-O) setting. Asterisks (*) indicate significant ($p<0.05$) preference over the reference (O-O) setting.

Statistical analysis

The Bradley-Terry Model as described by Critchlow and Fligner (1991) was used to statistically analyze the preference data. The bilaterally symmetrical omnidirectional (O-O) setting was arbitrarily selected as the reference and the likabilities of the remaining settings were calculated in relation to O-O. Likability is the logarithm of the ability of each setting, as defined by Critchlow and Fligner. It should be noted differences in likabilities cannot be compared across conditions. The likabilities of the various settings in each condition are shown in Fig. 7. The results can be summarized as follows:

1) S0ND: Some directionality was preferred over none at all. However, only the symmetrical directional (D-D) setting was significantly ($p<0.05$) more preferred than the symmetrical omnidirectional (O-O) setting.
2) S0NL: The settings with directionality in the left ear (D-O and D-D) were significantly ($p<0.05$) more preferred than the symmetrical omnidirectional (O-O) setting.
3) Restaurant, theatre: There were no significant ($p>0.05$) differences in preference across settings. This outcome is different from that for the standard stimuli

SUMMARY AND DISCUSSION

The main findings of this study can be summarized as follows:

1) The expectation that hearing aid users should subjectively perceive a directional advantage is reasonable. This is borne out by the fact that performance and perceptual SRTNs are similar, and the directional setting is preferred 5 times as often as the omnidirectional.
2) A significant directional preference is expected for speech understanding in noise. This expectation is borne in the S0ND condition where the bilaterally symmetrical directional (D-D) setting is preferred over the bilaterally symmetrical omnidirectional (O-O) setting. It is noteworthy that, the asymmetrical (D-O and O-D) settings are not significantly more preferred than the O-O setting.
3) Noise location is expected to influence directional preference. As expected, in the S0NL condition, directionality is preferred over omnidirectional in the left ear. The expected contribution of directionality in the right ear is less clear. This ambiguity is reflected in the non-significant preference for directionality in the right ear for a given microphone mode in the left ear.
4) The pattern of responses for the restaurant and theater conditions is expected to be similar to that for S0ND and S0NL, respectively. A slight (non-significant) trend for likability in favour of directionality is seen in the restaurant condition, which is in keeping with expectations. On the other hand, contrary to expectations, any directionality in the right ear (O-D and D-O) appears to be slightly disfavoured in the theater condition.

The departure from expectation for the real-world stimuli may be related to:

1) Test SNRs that were approximately 5 dB higher for the standard stimuli than for the simulated real-world stimuli. Although the pilot data suggested minimal variation in preference at different SNRs, there may be a complex interaction between SNR and increased difficulty of the task due to the asymmetrical microphone modes.
2) Use of the omnidirectional performance SRTN to set the test SNR for the standard stimuli. The resulting uniformity in difficulty for the standard stimuli likely contributed to a greater uniformity in responses for those conditions. In contrast, all participants in Group B evaluated the restaurant and theater at -2 and -4 dBSNR, respectively.
3) Background noise that is modulated and dynamic, much like the real world. Further, the noise was competing speech and music, which might otherwise be considered a signal. This may inadvertently result in a division of attention among the various sounds.
4) Informational masking that results when the signal characteristics are similar to that of the noise (Brungart *et al*., 2001). Although the effect did not achieve statistical significance, Hornsby and Ricketts (2007) showed ~1 dB lower directional benefit for speech than speech-like masker.

These findings have several implications for clinical practice. First, given the difficulty of the task, the occurrence of informational masking, the division of attention among sound sources and possibly searching for the appropriate hearing aid setting in the process, it is not surprising that patients often do not report a directional advantage in day-to-day life. Second, bilaterally symmetrical directional settings may not always be desired or necessary. It is conceivable that this would be even more true for off-center signals. Finally, we need to exercise caution in dismissing the efficacy of technology based only on patient report.

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