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The Impact of Listening with Directional Microphone Technology on Self-Perceived Localization Disabilities and Handicaps

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Abstract

The chief complaint of individuals with hearing impairment is difficulty hearing in noise, with directional microphones emerging as the most capable remediation. Our purpose was to determine the impact of directional microphones on localization disability and concurrent handicap. Fifty-seven individuals participated unaided and then in groups of 19, using omni-directional microphones, directional-microphones, or toggle-switch equipped amplification. The outcome measure was a localization disabilities and handicaps questionnaire. Comparisons between the unaided group versus the aided groups, and the directional-microphone groups versus the other two aided groups revealed no significant differences. None of the microphone schemes either increased or decreased self-perceived localization disability or handicap. Objective measures of localization ability are warranted and if significance is noted, clinicians should caution patients when moving in their environment. If no significant objective differences exist, in light of the subjective findings in this investigation concern over decreases in quality of life and safety with directional microphones need not be considered.

Key Words: Directional-microphones, Omni-directional Microphones, Self-perceived disability and handicap, Localization Disabilities, Localization Handicaps

Abbreviations: SNR = Signal-to-Noise Ratio; FAR = Front-to-Angle Ratio; SDI = Social Disengagement Index

Sumario

La principal queja de los individuos con trastornos auditivos es la dificultad para escuchar en medio de ruido, emergiendo los micrófonos direccionales como el más capaz remedio. Nuestro propósito fue determinar el impacto de los micrófonos direccionales en la incapacidad de localización y en los impedimentos concurrentes. Cincuenta y siete individuos participaron sin amplificación y luego, en grupos de 19, utilizando micrófonos omni-direccionales, micrófonos direccionales, o amplificación equipada con interruptores de palanca. La medida de resultado fue un cuestionario de discapacidades e impedimentos de localización. Las comparaciones entre el grupo sin amplificación versus los grupos con amplificación, y entre el grupo con micrófono direccional versus los otros dos grupos con amplificación no revelaron diferencias significativas. Ninguno de los esquemas de micrófono aumentó o disminuyó la discapacidad o el impedimento auto-percibido de localización. Las medidas objetivas de la habilidad de localización se garantizan y si se llega a notar algo significativo,

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los clínicos deberían advertir a los pacientes cuando se desplacen en sus ambientes. Si no existen diferencias objetivas significativas, a la luz de los hallazgos subjetivos de esta investigación, no debe considerarse ninguna preocupación sobre la disminución de la calidad de vida o la seguridad con el uso de micrófonos direccionales.

Palabras Clave: Micrófonos direccionales, Micrófonos omni-direccionales, Discapacidad e Impedimento auto-percibido, discapacidades de localización, Impedimentos de localización

Abreviaturas: SNR = Tasa de Señal/Ruido; FAR = Tasa Frente a Ángulo; SDI = Índice de Desapego Social

Because ameliorating the problem of hearing in noise is of primary importance to individuals with hearing impairment, it has been the primary objective of technological advances in amplification for several decades. Efforts have been made to develop circuitry that theoretically helps to reduce the effects of background noise with hearing aids. While theoretically sound, and despite some reports of a subjective preference for this type of circuitry (Boymans & Dreschler, 2000; Ricketts & Hornsby, 2005), the promise of benefit for speech-in-noise understanding from many of these "noise-reduction" circuits has not been realized in practice (Schwander, et al, 1984; Levitt, et al, 1986; and Levitt, 1987; Weiss, 1987; Levitt et al, 1993).

Research in the area of directional microphone technology has consistently produced reports of improved understanding of speech in noise in the laboratory setting (Nielsen, 1973; Sung et al, 1975; Mueller and Johnson, 1979; Hillman, 1981; Mueller, 1981; Mueller et al, 1993; Chasin, 1994; Valente et al, 1995; Agnew, 1997; Agnew and Block, 1997; Killion, 1997; Voss, 1997; Preves et al, 1999; Ricketts & Dhar, 1999; Wouters et al, 1999; Boymans and Dreschler, 2000; Christensen, 2000; Pumford et al, 2000; Cord et al, 2002; Surr et al, 2002; Cord et al, 2004; Walden et al, 2004). This type of technology appears to be the most adroit way to address the speech-in-noise issue. However, the extent to which this advantage is realized in the real world is less clear. Some studies suggest that the directional benefit derived in real-world listening situations is less than might be expected based on the benefit observed in the laboratory (Nielsen, 1973; Valente et al, 1995; Preves et al, 1999; Boymans and Dreschler, 2000; Cord et al, 2002; Surr et al, 2002; Cord et al, 2004; Walden et al, 2004). Various explanations for this discrepancy exist, the most prominent focusing on the potential overestimation of practical benefits of directional microphones when measured in laboratory settings (Amlani, 2001). In addition, some nuance of the complex interaction of the acoustic factors of the real-world environment may cause this difference in results (Dhar et al, 2004).

While communicating effectively in noise seems to be of highest priority for individuals with hearing impairment, a second utility of hearing is allowing the listener to sense their environment for safety and security. Evidence indicates that localizing is important to individuals with hearing impairment (Eriksson-Mangold et al, 1992). Noble et al (1995) showed that self-assessed disability associated with a decreased ability to localize was significantly associated with feelings of confusion and loss of concentration. Localization considerations are not only important as they pertain to gaining an understanding of hearing impairment in general, but also for understanding how the listening environment created through various types of amplification technology affects individuals with hearing impairment.

Hearing aids can disturb sound localization ability (Noble and Byrne, 1990; Byrne et al, 1992; Noble et al, 1998). The impact of listening in a directionally enhanced environment on the individual's ability to localize is unclear. The very properties of directional microphone technology that promote enhanced performance in noise may create problems in localization. Briefly, individuals use timing and intensity differences in sounds arriving at their two ears to localize the source of the sound (Zwislocki & Feldman, 1956; Tonning, 1975; Wightman & Kistler, 1992). Directional microphones use timing differences to determine which sounds come from in front of a listener versus which sounds come from other angles of incidence. The microphone is more sensitive to sounds coming from in front of the listener than to sounds coming from other angles of incidence. Therefore, the listener may be left unable to detect signals from much of the complex, real-world acoustic environment and unable to use naturally occurring intensity cues to help localize. It is not unreasonable to suggest that if localization is compromised when wearing directional microphone technology, then disability will be experienced in situations where localization is required. Individuals may withdraw from these situations because they do not feel safe, or may require assistance and/or companionship and therefore may experience a loss of independence. The impact that this aspect of enhanced directional hearing might have on activities of daily living has yet to be determined.

The purpose of this investigation was to determine the impact of directional listening on activities of daily living and feelings of safety and isolation among older individuals with impaired hearing.

The investigation included groups of individuals who 1) did not use amplification, 2) listened in an omni-directional, amplified environment, 3) listened in a directionally enhanced, amplified environment, or 4) had the freedom to choose the directional properties of the amplified environment. The specific research questions that were addressed included the following.

Does a significant difference exist between the self-perceived localization disabilities and/or handicaps of unaided individuals and those same people after listening either in an omni-directional, amplified environment, a directionally enhanced, amplified environment, or after wearing toggle-switch equipped hearing aids where the user has the freedom to choose the directional microphone properties of the amplified environment?

Does a significant difference exist between the self-perceived localization disabilities and/or handicaps of any of the three aided groups?

Hypotheses included:

1. The unaided group would have more self-perceived disabilities and handicaps associated with localization impairment than each of the amplified groups.

2. Being forced into directional listening at all times would cause greater problems with localization and as such this group was expected to have more self-perceived disabilities and handicaps associated with localization impairment than the group listening in an omni-directional, amplified environment.

3. The flexibility associated with being able to choose the directional setting of the listening environment, based on the communication setting, would eliminate any self-assessed localization disabilities and handicaps evidenced by individuals who listened only in a directionally enhanced, amplified environment.

METHODS

Test Materials

Through responses to an untitled questionnaire, Noble et al (1995) examined self-assessed everyday disability resulting from or associated with impaired localization capacity and concomitant handicaps. The questionnaire consists of questions divided into sections (Noble et al, 1995). Section I explores self-perceived disabilities (as defined by the World Health Organization [WHO], 1980) associated with decreased localization abilities. Section II allows quantification of self-perceived handicap (as defined by the WHO, 1980) directly attributable to localization disability. By observing the responses of individuals with hearing impairment both with conventional omni-directional amplification and without, a high positive correlation between localization disability and handicap due to localization was found. This indicates that those who perceive themselves to be disabled in terms of localization also experience handicaps that impact their quality of life because of this specific disability. This questionnaire appears to be an appropriate tool to investigate self-perceived disabilities and handicaps, associated with impaired localization, among individuals with hearing impairment and was used as the outcome measure in the present investigation. See Appendix A for a copy of this questionnaire.

Two other self-perception tools that explore aspects of localization are available. They include "The Speech, Spatial and Qualities of Hearing Scale (SSQ)" (Gatehouse and Noble, 2004) and two new subscales developed by Ricketts et al (2003) for the "Profile for Hearing Aid Benefit" (originally developed by Cox et al [1991]). The spatial hearing section of the SSQ is quite similar to Section I of the Noble et al (1995) questionnaire. A separate section, comprised of 12 questions designed to determine level of handicap has been used in comparison with the SSQ; however, these questions are not specific to handicap that is associated specifically with localization disability. The questions developed by Ricketts et al (2003) were designed to specifically address the situations in which directional hearing aids may provide different degrees of benefit than omni-directional hearing aids. However, these questions do not uncover potential localization disabilities or handicaps; therefore the Noble et al (1995) questionnaire is more appropriate for assessing both disability and resulting handicap and was chosen for the outcome measure used in the present investigation.

In a study completed by Flamme (2001) the internal consistency reliability of the "LOCATE" (Section I of the questionnaire developed by Noble et al, 1995) is shown to be 0.93 as determined by applying Cronbach's alpha. In a previous investigation by the present authors (Ruscetta et al, 2005) the internal consistency, test/retest reliability, and validity of both Section I and II of the Noble et al (1995) questionnaire were reported. A strong interrelationship was found among the items on the disabilities section (0.90) and among the items on the handicaps section (0.80). For Section I, these results compare well with those previously reported (0.93) (Flamme, 2001). Based on these measures, it can be said with confidence that each section of this measure examines a specific construct and that the questions within each section are similar in type as they relate to that construct.

The temporal stability of the scale was established by comparing participant responses from two separate occasions. Pearson's correlational analyses revealed test-retest reliability for Section I (Disabilities) at 0.90 and for Section II (Handicaps) at 0.70. Both correlations are significant at the 0.05 level ($p \leq 0.001$). This is a good tool to use if one means to apply it on multiple occasions.

A group likely to suffer from localization disability based on their type and degree of impairment could be identified (individuals with severe-to-profound unilateral hearing impairment), and their responses could be compared with those of a group who is unlikely to suffer from those same disabilities (individuals with normal hearing bilaterally). Two-tailed t-tests revealed significant differences between these groups at the 0.05 level for both the disability section ($p \leq 0.001$) and for the handicaps section ($p=0.008$). The results of this analysis support that this measure allows for a valid assessment of a participant's self-perceived localization disabilities. Also, though those same participants were not necessarily expected to suffer from handicaps related to those disabilities, this measure does appear to allow an accurate assessment of such handicaps if they do exist. Thereby, the construct validity of this scale has been established.

These psychometric data indicate that this measure allows for a valid and reliable assessment of both participant's self-perceived localization disabilities and concurrent handicaps if they exist.

Research Design

This was an experimental study that employed both within and between group comparisons. As noted, the outcome measures were responses to a questionnaire developed by Noble et al (1995) that uses a four option forced choice response method. Each response is assigned a number from one to four, and a four always represents the least amount of difficulty.

Participants

Fifty-seven 60-75 year old participants with moderate, symmetrical, bilateral sensorineural hearing loss participated. See Table 1 for participant characteristics.

A power analysis was used to determine the appropriate number of participants assuming a medium effect size, a desired power of 0.80, and an alpha of 0.05. This effect size was reasonable given the variability and the size of the effects observed in previous studies using this questionnaire (Noble et al, 1995).

When recruited for participation, each participant was informed that they would be randomly assigned to participate in either; a) one group who would use hearing aids with microphones with equal sensitivity from all directions, b) one group who would use hearing aids with microphones that were more sensitive to the sounds that come from in front of the listener than to those sounds that come from other angles, or c) one group who would have both types of microphones available for use and a toggle-switch for choosing the microphone setting. They also were informed that in order to give every participant an opportunity to experience both types of microphones, the toggle-switch type instrument would be available for use and purchase after the experiment was complete and that currently there exists no evidence to suggest which of the three microphone configurations is best. Participants were provided $15.00 for miscellaneous expenses associated with participation and the option to pur-

Table 1. Participant Characteristics

	Gender		Average Age (Age Range)	Average Duration of Hearing Loss	Duration of Hearing Loss Range
	Male	Female			
Unaided Group (N = 57)	38 (67%)	19 (33%)	66.6 (60-75) years	9.07 years	4 mo. – 50 years
Omni-Directional Only Amplified Subgroup (N=19)	15 (79%)	4 (21%)	65.95 (60-75) years	8.5 years	6 mo. – 50 years
Directional-Only Amplified Subgroup (N=19)	11 (58%)	8 (42%)	66.47 (60-75) years	8.42 years	2 – 30 years
Toggle Switch Equipped Amplified Subgroup (N=19)	12 (63%)	7 (37%)	67.42 (60-75) years	10.28 years	4 mo. – 30 years

chase their hearing aids at the conclusion of the study at approximately 50% off of the manufacturer's charge.

The acceptable range of hearing loss (see below) was dictated by the amount of hearing loss expected to make at least high-frequency sound inaudible yet not so much hearing loss that sound could not be made audible through amplification. All participants presented with symmetrical sensorineural hearing loss.

The majority of hearing aid users continue to be older adults and this is the population of interest in this study. Evidence suggests that central decline progresses somewhat gradually from the fifth decade on (Pestalozza, and Shore, 1955; Harbert et al, 1966; Konkle et al, 1977; Birren et al, 1980; McCroskey and Kasten, 1982; Otto and McCandless, 1982; Schmitt, 1983; Stach et al, 1985; Jerger et al, 1989a; Jerger et al, 1989b; Stach et al, 1990; Gates and Cooper, 1991; Jerger et al, 1991; Jerger, 1992; Letowski and Poch, 1995). This decline appears to become more steeply sloping at around age 75 years. Therefore, the age group for this experiment was limited to 60-75 years.

Two other exclusion criteria were applied. All participants were free of any documented brain injuries, because of the impact that this type of insult may have had on their responses to the questionnaire. Also, given the nature of the questions on the survey, it was important that the individuals participate in activities that allowed them to complete the questions on the outcome measure. Therefore, the Social Disengagement Index (SDI) (Bassuk et al, 1999) was administered. With this scale, a composite SDI can be obtained which is based on six social constructs; 1) Spouse, 2) Visual, 3) Non-visual, 4) Church, 5) Groups, and 6) Social activities. While the measure was completed by each participant in its entirety, because the purpose of administering this scale was to determine if the individual participated in outside activities, a score of "one social tie" on the social activities construct was accepted for inclusion in the present investigation. These inclusion and exclusion criteria were applied to each of the four experimental groups described below.

Unaided Group

The unaided group was made up of fifty-seven participants. These participants (38 males, 19 females; age range: 60-75 years; mean age: 66.6 years) presented with moderate, bilateral symmetrical sensorineural hearing loss and no prior hearing aid experience. Thresholds at 250 and 500 Hz did not exceed 40 dB HL. Thresholds were between 0-60 dB HL at 1000 and 2000 Hz, and were no worse than 70 dB HL at frequencies from 3000 Hz and above. The average PTA for this group was 31.97 dB HL. The range of PTAs was from 6.67 dB HL to 55.83 dB HL. See Figure 1 for the unaided group's average audiogram.

Aided Groups

Each of the fifty-seven participants from the unaided group was randomly assigned to participate in one of three aided groups of nineteen participants each, where they were fit bilaterally with Siemens custom, in-the-ear style, MUSIC hearing aids equipped with a first-order, hypercardioid, directional microphone with an average reported free-field directivity index of 5.3 dB. This directional microphone allows the hearing aid to function with directional properties. For one group (the omni-directional only group), the hearing aids functioned only in the omni-directional mode for the duration of the investigation. For the second group (the directional-only group), the hearing aids functioned only in the directional mode for the duration of the investigation. For the final

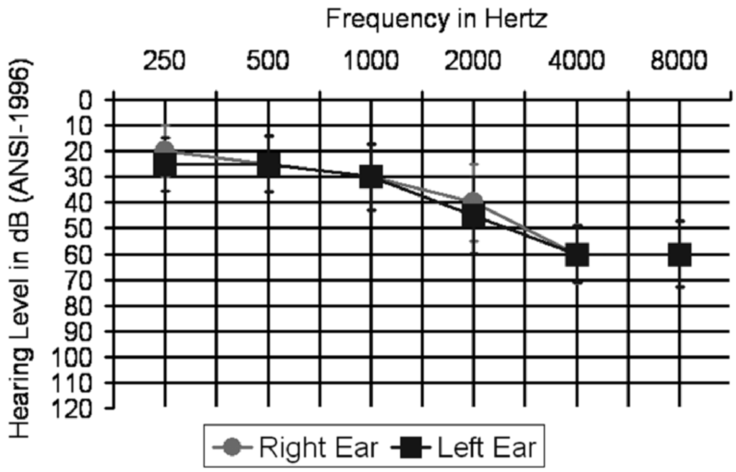

Figure 1. Unaided Group Average Audiogram – Error bars represent one standard deviation.

group (the toggle-switch equipped group), a toggle-switch allowed the user to switch between both modes of listening (omni-directional versus directional).

Omni-directional Only Group. This group of nineteen individuals included 15 males and 4 females (age range: 60 – 75 years; average age: 65.95 years). The average PTA for this subgroup was 32.54 dB HL (range 15.83 – 55.83 db HL). See Figure 2 for the average audiogram for this subgroup.

Directional-Only Group. This group of nineteen individuals included 11 males and 8 females (age range: 60 – 75 years; average age: 66.47 years). The average PTA for this subgroup was 32.85 dB HL (range 14.17 – 50 dB HL). See Figure 3 for the average audiogram for this subgroup.

Toggle-Switch Group. This group of nineteen individuals included 12 males and 7 females (age range: 60 – 75 years; average age: 67.42 years). The average PTA for this subgroup was 32.54 dB HL (range 15.83 – 55.83 dB HL). See Figure 4 for the average audiogram for this subgroup.

PROCEDURES

Session One - Unaided Participation

Unaided participation was completed with each participant at session one. Standard audiometric procedures were used to obtain thresholds and confirm eligibility through air conduction between 250 – 8000 Hz and bone conduction between 500 – 4000 Hz (ANSI, S3.6 – 1978 [R 1997]). During the hearing evaluation, uncomfortable loudness level (UCL) measurements also were obtained to allow confirma-

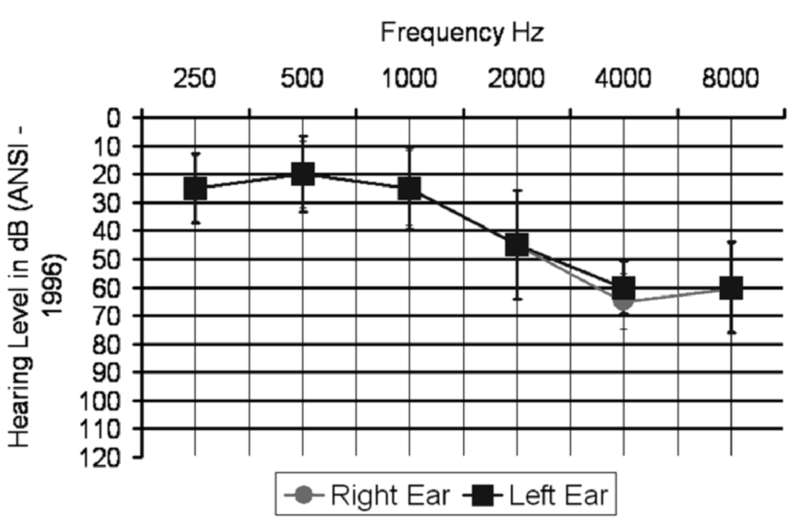

Figure 2. Omni-directional Only Group Average Audiogram - Error bars represent one standard deviation.

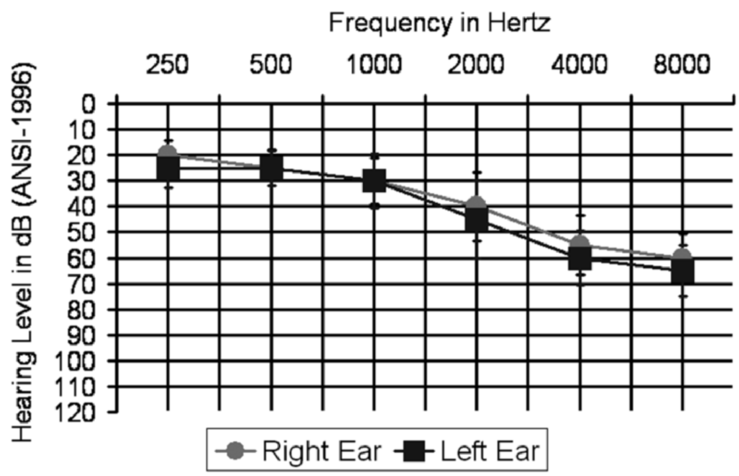

Figure 3. Directional-only Group Average Audiogram - Error bars represent one standard deviation.

tion that the hearing aids that were later fit provided amplification that did not allow sounds to exceed the UCL. UCL tests were administered at each frequency from 500-4000 Hz (Jesteadt, 1980). To further confirm eligibility, the aforementioned SDI (Bassuk et al, 1999) was administered. Each participant was then asked to complete sections I and II of the localization questionnaire prior to being fit with amplification.

Session Two

Hearing Aid Fitting – All Participants

Each participant was fitted bilaterally with Siemens custom, in-the-ear style, MUSIC hearing aids equipped with a first-order, hypercardioid, directional microphone with an average reported free-field directivity index of 5.3 dB. For the omni-directional only group, the directional microphone was not enabled and no toggle-switch was available. For the directional-only group, the directional microphone was enabled, and no toggle-switch was available. For the toggle-switch group, both the omni-directional and directional microphones were available and a toggle-switch on the face plate allowed users to choose which microphone to use in any given listening situation. Individuals from the toggle-switch equipped group were instructed that they should experiment with the directional microphone in different settings. They were provided with suggested situations where it was believed that the directional microphone would be the optimal choice (i.e., in a restaurant where their companion was seated across from them).

Real ear probe microphone measurements were performed in order to ensure that the hearing aids were providing amplification that allowed soft (50 dB SPL), moderate (70 dB SPL), and intense (90 dB SPL) sounds to be both audible and comfortable across frequencies (500 Hz – 4000 Hz). The hearing aid

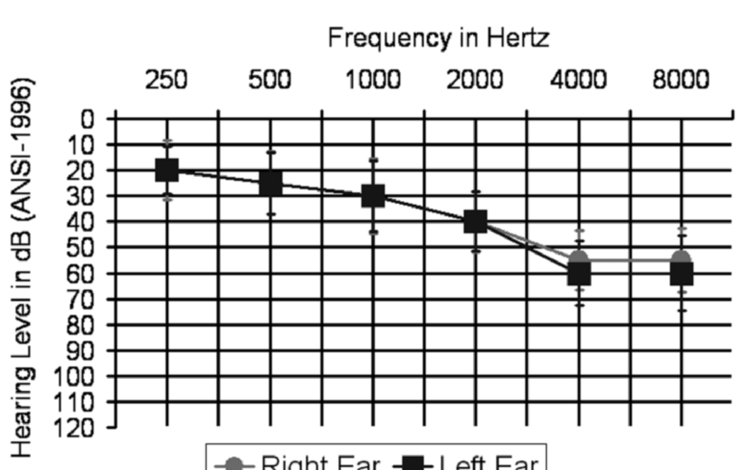

Figure 4. Toggle-switch Group Average Audiogram - Error bars represent one standard deviation.

parameters (overall gain, cross-over frequency, low channel compression ratio and knee point, and high channel compression ratio and knee point) were manipulated until audibility and comfort of soft (50 dB SPL), moderate (70 dB SPL), and intense (90 dB SPL) sounds at 500 – 4000 Hz were verified to be above threshold displayed in SPL and below UCL displayed in SPL in the omni-directional and directional settings.

Hearing Aid Fitting - Participants with Directional Microphone Capabilities

The directional properties of the hearing aids were verified for each set of hearing aids, worn by each individual, by obtaining front-to-angle ratios (FARs). The FAR is the advantage in microphone sensitivity measured in decibels for sounds that originate from directly in front of the listener over sounds originating from other angles of incidence. For this experiment, FARs were obtained by subtracting the output of the hearing aid at 90°, 135°, 180°, 225°, and 270° from that obtained from signals presented at 0° azimuth. Killion et al (1998) found that for every decibel of signal-to-noise ratio (SNR) improvement, an increase of approximately 9% can be obtained for scores for words-in-sentences on the Speech in Noise (SIN) test. Individuals who participated in Killion et al (1998) experienced a 20-60% improvement on word scores using directional microphones in different reverberant environments where SNR advantages of 3-8 dB were obtained. The hearing aids used in the present investigation were required to and did evidence FARs of at least 3 dB at each angle of incidence tested.

All participants were encouraged to wear the hearing aids full time in a variety of day-to-day listening situations for a period of three months. They also were encouraged to call if any problems arose. Nine participants (three from the omni-directional microphone only group, two from the directional microphone only group, and four from the toggle-switch equipped group) returned with problems that required adjustments to be made to the hearing aid parameters. Depending on the complaint, overall gain, cross-over frequency, low channel compression ratio and/or knee point, and high channel compression ratio and/or knee point were adjusted to address the problem. Once manipulation was complete, real ear probe microphone measurements were performed to ensure that the hearing aids still provided audibility and comfort for soft, moderate, and intense sounds at 500-4000 Hz. The three month experimental wearing period began again for these nine individuals on the day that the adjustments were made.

Session Three – Three Months Post-fitting Participation

At session three, each participant was asked to complete Sections I and II of the questionnaire. For those with directional microphone capabilities, the FAR measurements were repeated to ensure that the hearing aids were still functioning with at least a 3 dB directional benefit at each azimuth.

All participants were then asked to decide if they wished to purchase the hearing aids at a significantly reduced cost. Participants were aware of this option at the beginning of the study and that they were under no obligation to purchase amplification. Therefore this benefit was not expected to bias these participants. When participants from the directional-only or omni-directional only group opted to purchase their hearing aids, the toggle switch option was added and enabled at that time. A total of 25 participants (44%) opted to purchase either one or both of their hearing aids: ten (40%) from the omni-directional microphone only group, eight (32%) from the directional-microphone only group, and seven (28%) from the toggle-switch equipped group. There does not appear to have been a significant bias for any one subgroup's participants to purchase their instruments.

STATISTICAL CONSIDERATIONS

Group mean total scores from items 1 through 9 from Section I of the questionnaire were used to establish the amount of self-perceived disability for discrimination of the location of sounds for each group. From Section II, group mean total scores from items 17 and 18 were used to reveal self-perceived limitations on independent activity. Given that when multiple comparisons are performed, the Dunn method (Glass and Hopkins, 1996) can be used to control the Type I error rate and the decision to apply the Dunn method should be based on the consequences of generating a Type I error versus those of generating a Type II error, the possible outcomes for each of the five proposed research questions were reviewed as well as the actions that would be taken given each outcome. Because the most serious erroneous consequence occurs because of a Type II error

Table 2. Group Mean Total Scores for Disability Section Questions 1-9 and Handicap Section Questions 17 and 18 for Paired Samples t-tests Comparisons.

Group	Group Mean Total Scores Disability Section Questions 1-9		Group Mean Total Scores Handicaps Section Questions 17 & 18	
Omni-directional only Group	Unaided 3.05	Aided 3.06	Unaided 3.84	Aided 3.92
Directional-only Group	Unaided 3.04	Aided 3.14	Unaided 3.74	Aided 3.87
Toggle-switch equipped Group	Unaided 3.20	Aided 3.33	Unaided 3.84	Aided 3.82

(unsafe environment), but the second worst erroneous consequence occurs because of a Type I error (losing the benefit of wearing directional microphone technology), it was determined that the alpha level would be left at p = 0.05 for the most appropriate analysis and interpretation of these data.

RESULTS

In order to answer the research questions about unaided versus aided responses, using paired samples t-tests, the unaided group mean total scores based on responses to questions 1 through 9 from the nineteen participants assigned to each of the hearing aid groups were compared to those same nineteen participant's aided group mean total scores based again on responses to questions 1 through 9. These analyses also were applied to the mean total scores based on responses to questions 17 and 18 from the handicaps section of the questionnaire. Table 2 provides the group mean total scores used in these comparisons.

No significant differences were found between any of the groups' self perceived level of ability to tell the direction of sounds or amount of withdrawal from activities of daily living (ADLs) due to inability to localize before being fit with amplification versus after having worn either omni-directional microphone only hearing aids (p = 0.93 and 0.27 respectively), directional microphone only hearing aids (p = 0.49 and 0.49 respectively), or toggle-switch equipped hearing aids (p = 0.39 and 0.33 respectively).

In order to answer the research questions pertaining to aided performance comparisons, an ANCOVA was applied to the aided group mean total scores of all three aided groups for questions 1 through 9 and for questions 17 and 18 with each group's unaided group mean total scores acting as the covariate. Table 3 provides the adjusted aided group mean total scores used in these comparisons.

No main effect differences were found for the ANCOVA-adjusted self-perceived level of ability to tell the direction of sounds (p = 0.45) or for amount of withdrawal from ADLs (p = 0.61).

DISCUSSION

People with sensorineural hearing impairment who seek remediation do so primarily in order to be able to communicate better, specifically when trying to understand speech in a background of noise. Therefore, hearing aids have been designed to use technology aimed chiefly at ameliorating this problem. Currently, the most competent way to meet this goal with personal amplification is through the use of directional microphones. Research in this area has shown improved performance with understanding speech in noise at least in the laboratory setting. Unfortunately, the amount of benefit experienced in real-world listening situations has not been to the extent that might be expected from laboratory results. For example, in highly reverberant environments, the benefits of directional microphone technology cannot be realized because competing messages (i.e., noise) are reflected in the frontal plane and are not reduced as desired.

The first three research questions in this investigation asked if there was a significant difference in the responses of unaided individuals and of those same individuals after having worn amplification with omni-directional microphones, directional-only microphones, or hearing aids equipped with a toggle-switch. It was hypothesized that wearing any type of microphone configuration on amplification (omni-directional, directional-only, or toggle-switch equipped) fit so that all frequencies between .5 and 4 kHz were audible would allow significant improvement in the self-perceived level of ability to tell the location of sounds and significant decrease in the level of withdrawal from activities where localization disability is potentially problematic. Using the same questionnaire, Noble et al 1995 obtained reports of increased self-perceived localization abilities when using

Table 3. Adjusted Aided Group Mean Total Scores for Disability Section Questions 1-9 and Handicap Section Questions 17&18 for ANCOVA

Group	Group Mean Total Scores Disability Section Questions 1-9		Group Mean Total Scores Handicaps Section Questions 17 & 18	
Omni-directional only Group	Unadjusted Aided 3.06	Adjusted Aided 3.08	Unadjusted Aided 3.92	Adjusted Aided 3.91
Directional-only Group	Unadjusted Aided 3.14	Adjusted Aided 3.17	Unadjusted Aided 3.87	Adjusted Aided 3.90
Toggle-switch equipped Group	Unadjusted Aided 3.33	Adjusted Aided 3.28	Unadjusted Aided 3.82	Adjusted Aided 3.80

either one or two omni-directional only hearing aids as compared to the unaided condition. Interaural intensity cues are one of the primary indicators used to localize. Because many of the sounds that are important for localization are inaudible to the individual with moderate sensorineural hearing impairment, restoring the ability to hear these otherwise inaudible cues should allow one to localize better.

Because timing and intensity cues are among the properties that are altered with the use of directional microphone technology and are the primary determinates for successful localization, it also was hypothesized that individuals with moderate sensorineural hearing impairment, who wore only directional microphone technology, would identify a significantly lower level of ability to tell the location of sounds and greater level of withdrawal from activities where localization disability is potentially problematic than those who wore omni-directional only amplification.

None of these hypotheses were supported. In the case of the unaided versus aided comparisons, no significant differences between the unaided responses versus the aided responses were found. Stated differently, wearing hearing aids did not significantly increase or decrease the participants' self-perceived level of ability to tell the direction of sounds nor did it significantly increase or decrease their level of withdrawal from activities where the ability to localize is likely to be important.

The above results appear to be in direct contrast to those found by Noble et al (1995) in that a significant difference was not noted between the responses of the unaided group and of those wearing omni-directional microphone only amplification. The likely explanation for this discrepancy lies in differences in the participant demographics between the two studies as well as the treatment of the data. The participants in the Noble et al (1995) study differed from the present investigation's participants in three important ways. The sample from the earlier investigation had a much larger age range and a higher average age than any of the main experiment groups examined in the current study.

The average better-ear hearing threshold levels for the Noble et al (1995) group were 4.2 – 16.2 dB HL worse than the corresponding thresholds for the group used in the present experiment. The four frequency average hearing level (average of the better-ear thresholds at .5, 1, 2, and 4 kHz) was 10.5 dB HL worse for the Noble et al (1995) participants.

Each of the individuals who participated in the Noble et al (1995) investigation had previous amplification experience prior to answering the questionnaire in the "unaided" condition. This particular difference could have a profound effect on the difference between the results found in the earlier investigation versus the present investigation. Individuals who are comparing performance ability when their hearing aids are turned off versus having never worn hearing aids are likely to have a very different perception of their abilities.

Another important difference between the two investigations lies in the treatment of the data. Noble et al (1995) state that because some respondents answered some negatively worded items as though they were positively worded, rather than try to second guess what respondents had intended, the results from negatively worded items (#2, 4, 7, 11, and 13) were excluded from analysis. This was not the case for the present investigation. A response was obtained for each question, and as the questionnaires were completed in the presence of the investigator, when any discrepancies in the theme of responses by an individual were present, the intended response of the participant was confirmed. In addition, items 10-14 were not used in the present analyses as it was determined a priori that only those items that revealed possible limitations on the ability to tell the location of sounds (as opposed to the distance of sounds) would be examined.

It was assumed from the wealth of data available about the localization abilities of individuals with hearing impairment that the participants in this investigation would have significantly more self-perceived localization disabilities and handicaps than those with normal hearing. Because the results of this experiment deviated from expectations, six t-test comparisons were performed to see if significant differences existed between the mean total scores for questions 1-9 and 17 &18, for the 20 individuals with normal hearing from Ruscetta et al (2005) versus the unaided responses of the 19 participants from each aided subgroup from the present experiment. It was found that each of the three groups of participants with hearing impairment identified a significantly lower level of ability to tell the location of sounds than the group with normal hearing from the previous study. The finding of this expected difference between individuals with normal hearing and those participants with hearing impairment in the current investigation illustrates that the potential did exist for significant improvement with the use of amplification and allows us to be more certain that the results are a valid representation of the state of self-perceived localization and not the product of an erroneous methodology.

However, none of the unaided groups with hearing impairment evidenced a significant difference in level of withdrawal from activities where localization is potentially an issue than the group with normal hearing, leaving no room for significant improvement with hearing aids on this factor. Although the participants with hearing impairment perceived more disability than those with normal hearing, they did not let this impact their participation in these activities.

The true effect size, or the amount of difference in level of disability or handicap allowed by providing amplification, was shown to be quite small. A priori, based on the work of Noble and colleagues (1995), the effect size was assumed to be medium. The amount of effect that amplification actually has on the scores may be too small to be meaningful as evidenced by the great number of individuals who would be needed per group to find a significant difference given the true size of the effect in the present investigation.

The measure used in this study, which was shown to have construct validity with groups who could be expected to respond at the extremes of the scale (i.e., those with normal versus unilateral hearing impairment) may not be as well suited to revealing more moderate levels of localization disability and/or handicaps associated with impaired localization, as is quite likely the case for those with moderate bilateral hearing impairment. For example, perhaps the situations described need to have more detail or perhaps more or different situations need to be included.

Finally, it is possible that some other psychoacoustic factor(s) necessary for localization, other than lack of audibility of timing and intensity cues, is (are) impaired in those with hearing loss and is (are) the reason that restoring audibility through amplification is not sufficient to improve self-perceived ability to tell the direction of sounds and subsequently reduce the amount of withdrawal from situations where the ability to localize is a factor. One potential culprit is an inability to take advantage of spatial cues. Noble and Perrett (2002) found that in parsing the auditory array, attention to spatial cues is heightened when the components of the array are confusable on other acoustic grounds, for example, when the noise and the signal are both speech signals or are both speech signals spoken by females or both spoken by males. Additionally, laboratory results have shown that directional benefit is influenced by the amount of spatial separation between signal and noise sources (Leeuw and Dreschler, 1991; Ricketts, 2000).

This latter theory can be expanded upon to explain why significant deterioration was not seen with directional-only amplification versus omni-directional amplification or toggle-switch equipped amplification in the current study. Rather than the directional-only microphones making the localization situation worse by confusing timing and intensity cues, none of the hearing aids may have overcome or addressed the factors that are impaired in the listener that were needed to re-establish normal localization ability. Again, for example, none of the hearing aids used in this investigation are designed to improve the amount of spatial separateness associated with the signal and noise. When localization abilities are impaired because of hearing loss, just like in the case of speech recognition ability, simple intensity restoration may not be enough to return performance to pre-hearing loss levels.

Although differences in the self-perceived level of localization abilities were not evidenced in this investigation, objective measures of localization ability with directional microphone amplification have not been assessed to date. Future research should include a replication of this study using objective outcome measures of localization ability. Also, a comparison of the responses of individuals with hearing impairment with those of their significant others could yield interesting results in terms of perception of ability and participation.

CONCLUSION

It appears that hearing aids with omni-directional microphones, directional-only microphones, and those that are equipped with a toggle-switch allowing a choice of the directional properties of the instrument neither increase nor decrease the self-perceived level of ability to tell the direction of sound or the level of withdrawal from situations where localization ability is a factor. Concurrently, directional-microphone-only technology does not significantly worsen or make better these factors as compared to the other two microphone configurations. Future research should include objective measures of localization ability using the same paradigm. Additionally, it would be interesting to see if similar results bear out with individuals wearing automatic adaptive directional microphones where the directional properties of the instrument are ever changing. If ultimately no significant differences in either objective or subjective measures are found, then concern over decreases in quality of life and safety with directional microphone use need no longer be considered.

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Appendix A.

Questionnaire for Disabilities and Handicaps Associated With Localization

Section I – Localization

1. You are at home in a quiet room. There are other people in the house (friends or family). They are talking in another room and you can hear them. Can you tell which part of the house those people are in?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

2. Do you turn the wrong way when some-one that you can't see calls out to you?
   1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

3. You are outdoors in an unfamiliar place. You can hear the sound of someone mowing a lawn. You can't see where they are. Do you know where the sound is coming from?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

4. You are sitting around a table or at a meeting with several people. There is some background noise. You can't see everyone. Do you find it hard to know which person is speaking?
   1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

5. You are in an unfamiliar house. It is quiet. You hear a door slam. Can you tell what part of the house the sound came from?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

6. You are in a high-rise apartment or office building. You can hear sound from another floor. Can you tell whether the sound is coming from above or below you?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

7. You are standing on the footpath of a busy street. A car horn sounds. Do you have difficulty telling which direction it came from?
   1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

8. You are outside. A dog barks loudly. Can you tell where it is without having to look?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

9. You are standing on the footpath of a busy street. Can you hear which direction a bus or truck is coming from before you see it?
   1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

10. In the street, can you judge how far away someone is, from the sound of their voice or footsteps?
    1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

11. You are outdoors in an unfamiliar place. Someone calls out from somewhere above you (such as a balcony or bridge). Do you find it hard to tell where the voice is coming from?
    1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

12. You are standing on the footpath of a busy street. Can you tell, just from the sound, roughly how far away a bus or truck is?
    1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

13. You are outside. You can hear an airplane. Do you find it hard to tell where the plane is in the sky, by the sound alone?
    1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

14. If you have a problem telling where something is coming from, does it help if you move around to try to locate the sound?
    1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

Section II – Handicap

15. Are you a confident person?
 1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

16. You are in a place that is unfamiliar to you. Do you get nervous or feel uncomfortable in this situation because of trouble telling where sounds are coming from?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

17. Does difficulty telling where sounds are coming from lead you to avoid busy streets and shops?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

18. Because of difficulties telling where sounds come from, is a visit to the shops something you don't do by yourself?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

19. You are invited into a stranger's home. Do you feel less at ease in the stranger's home than in a home that is familiar to you?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

20. If you are in a busy place, such as a crowded shopping center or city street, do the sounds you hear seem all mixed up or confused?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

21. When sounds are mixed up or confused, does this cause you to feel confused or unsure about exactly where you are?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

22. Does wearing your hearing aid(s) reduce any feelings of confusion you may experience?
 1) Almost never, 2) Sometimes, 3) Often, 4) Almost Always

23. When sounds are mixed up or confused, does this cause you to lose concentration on what you were doing or thinking?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

24. You are in a place where sounds seem mixed up and confused. You are by yourself. Do you feel a need to leave that place quickly to go to a place where you will feel more comfortable?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never

25. Does wearing your hearing aid(s) increase any feelings of confusion you may experience?
 1) Almost Always, 2) Often, 3) Sometimes, 4) Almost never