Influence of Environmental Factors on Hearing Aid Microphone Preference

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Abstract
The purpose of this study was to identify characteristics of everyday listening situations that influence user preferences for omnidirectional versus directional hearing aid microphones. Eleven experienced hearing aid users were fitted with digital hearing aids featuring switchable omnidirectional (OMNI) and adaptive-directional (DIR) modes (programs). For 6 weeks, their task was to identify and describe at least one listening situation each day in which one program performed better than the other using a checklist daily journal format. All participants reported difficulty identifying situations in which they could perceive a difference between the two microphone modes. Although an equal number had been requested, descriptions favoring the DIR outnumbered those for the OMNI. Chi-square tests were used to compare the distributions of 60 descriptions favoring the OMNI and 155 favoring the DIR across variables associated with the primary talker to whom the hearing aid user was listening, background noise, and other environmental characteristics. The results indicated that location of the primary talker, presence or absence and type of background noise, and type of space in which the communication occurred influenced microphone choice.

Key Words: Adaptive-directional microphones, descriptions of listening situations, microphone preference, omnidirectional microphones, wide dynamic range compression

Abbreviations: CST = Connected Speech Test; DIR = directional mode of hearing aid; OMNI = omnidirectional mode of hearing aid; PHAB = Profile of Hearing Aid Benefit; rau = rationalized arcsine units; WDRC = wide dynamic range compression

Sumario
El propósito de este estudio fue identificar las características de aquellas situaciones cotidianas de escucha que influyen en las preferencias del usuario en cuanto a micrófonos direccional vs. omnidireccional. Once experimentados usuarios de audífono fueron adaptados con auxiliares auditivos digitales que contenían modos (programas) intercambiables de tipo omnidireccional (OMNI) y direccional adaptativo (DIR). Por 5 semanas, su tarea fue la de identificar y describir al menos una situación de escucha por día en la que un programa funcionara mejor que el otro, utilizando un formato de bitácora con una lista de anotación diaria. Todos los participantes reportaron dificultad en identificar situaciones en las que podían percibir una diferencia entre las dos modalidades de micrófono. Aunque se solicitó un número igual de reportes, las descripciones que favorecían el modo DIR superaron aquellas del OMNI. Se utilizaron pruebas de chi-cuadrado para comparar la distribución de 60 descripciones a favor del OMNI y 155 a favor del DIR, considerando variables asociadas con el interlocutor primario a quien el usuario del auxiliar auditivo escuchaba: ruido de fondo y otras características ambientales. Los resultados indicaron que la localización del interlocutor primario, la presencia o ausencia y el tipo de ruido de fondo y el tipo de espacio en el que ocurrió la comunicación, influyeron en la escogencia de micrófono.

Palabras Clave: micrófonos direccionales adaptativos, descripciones de situaciones de escucha, preferencia de micrófono, micrófonos omnidireccionales, compresión de rango dinámico amplio

Abreviaturas: CST = prueba de lenguaje conectado; DIR = modo direccional de auxiliar auditivo; OMNI = modo omnidireccional de auxiliar auditivo; PHAB = Perfil de Beneficio del Auxiliar Auditivo; rau = unidades racionalizadas de arcoseno; WDRC = compresión de rango dinámico amplio

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Recent laboratory studies have shown significant improvement in speech recognition in noise with directional microphones compared with omnidirectional microphones (Valente et al., 1995; Ricketts and Dahr, 1999). This difference between the two microphone modes is referred to as a directional benefit or advantage. Although benefit from directional microphones has been documented in everyday listening (Killion et al., 1998; Preves et al., 1999), several studies suggest that directional advantages comparable with those observed under laboratory conditions are not observed in listening environments typically encountered in daily living (Nielsen and Ludvigsen, 1978; Valente et al., 1995). This discrepancy between laboratory and field data may be because laboratory measures tend to overestimate the directional advantage that would actually be obtained in everyday listening (Amlani, 2001). The specific test conditions typically used in the laboratory involve the signal being presented from the front and the noise from the sides and/or back of the listener. Such conditions should favor directional microphones. Laboratory results have also shown that directional benefit is influenced by the amount of spatial separation between signal and noise sources and by the amount of reverberation introduced (Leeuw and Dreschler, 1991; Ricketts, 2000). As the environmental conditions encountered in everyday listening deviate from typical laboratory test conditions, the directional advantage is diminished (Studebaker et al., 1980; Madison and Hawkins, 1983; Hawkins and Yacullo, 1984).

Ricketts and Mueller (1999) explored possible listener variables in directional benefit. They examined the results of three laboratory investigations of directional benefit and observed that some listeners receive significantly more benefit from directional microphones than others. However, audiometric slope, degree of high-frequency hearing loss, and performance level in the omnidirectional mode were not predictive of directional benefit. Their results, therefore, provide further support for environmental factors being the critical determinant in directional benefit.

The results of a recent clinical trial of a digital hearing aid with an omnidirectional/directional option at the Army Audiology and Speech Center (Walden et al., 2000) also illustrated the disparity between laboratory and field data. Speech recognition scores in noise showed highly significant directional advantages, but subjective ratings showed minimal directional benefit in daily use. Walden and colleagues (2000) suggested a number of possible explanations for the discrepancy in directional microphone benefit observed between laboratory conditions and everyday use, including the likelihood that most real-life listening situations may not closely match the laboratory conditions.

Although a variety of factors may contribute to a directional advantage, it appears that the benefit obtained from either microphone type is particularly dependent on the physical characteristics of the listening environment. From this perspective, only when a specific set of environmental conditions exists in everyday listening does one or the other microphone mode provide superior performance. The present study was designed to identify characteristics of everyday listening situations that are likely to influence user preferences for either omnidirectional or directional microphones, using a new generation of directional microphone technology.

**METHOD**

**Subjects**

Participants were older adults with gradually sloping, moderate sensorineural hearing losses and relatively good speech recognition scores. They had acquired symmetric hearing losses (no interaural difference of greater than 20 dB HL from 500–6000 Hz) and were regular and relatively satisfied binaural hearing aid users. The clinical profile, including history and immittance measures, was consistent with a cochlear site of lesion.

Eleven adults meeting the selection criteria were recruited for the study. All participants were male, reflecting the predominantly male patient population from which they were recruited. The mean age of the participants was 71.1 years (SD = 6.0, range = 56–77 years). The average number of years of hearing aid use was 12.6 years (SD = 4.2, range = 8–20 years). At the time of enrolment in the study, three participants were hearing aids with wide dynamic range compression (WDRC) circuits, four with automatic gain control with input limiting circuits, and four with linear circuits. They were in-the-ear style instruments for 10 participants and behind-the-ear style for the remaining person.

In every case, the instruments were equipped with omnidirectional microphones only. The mean audiogram for each ear is shown in Figure 1. The average Northwestern University Auditory Test No. 6 scores (a 50-word list in the
Department of Defense and Veterans Affairs Audiology Materials, Disc 1.0® administered at comfortable levels under earphones were 77.2 percent (SD = 7.5, range = 64–88%) for the right ear and 72.2 percent (SD = 9.2, range = 52–88%) for the left ear.

Hearing Aids

All participants were fitted with binaural GN ReSound Canta7 BTE model 770-D behind-the-ear instruments. The Canta7 is an open-platform digital, multiband, multimemory hearing aid with a variable WDRC circuit. The syllabic compression threshold is 40 to 48 dB SPL, and the compression ratio ranges from 1:1 to 3:1 (program dependent in each band). The instrument has no user-operated volume controls. Six "handles" are provided for programming the gain parameters. For the participants in this study, the mean compression ratios (ranges in parentheses) for the six frequency bands are shown in Table 1. The right and left ear fittings have been combined here because the differences between the means were no greater than 0.1 for each handle.

In addition to multiband fast-acting WDRC, the Canta7 series includes optional microphone directionality. Directionality is achieved electronically through a two-microphone system and features an adaptive polar pattern option, as well as several fixed pattern choices. The adaptive polar response was used throughout this study. The adaptive directionality system of the Canta7 samples and frequently updates (250 times per sec) the null of the polar pattern toward the direction of the dominant noise located behind, to the sides, or somewhere in between. The first two memories were programmed with the manufacturer’s “basic program” using the participant’s hearing threshold data. In counterbalanced order, adaptive directionality was programmed into one of these two memories. These two programs will be hereafter designated OMNI and DIR. The manufacturer’s guidelines were used for fine-tuning of the fitting during the first 2 weeks of hearing aid use. No changes in the prescribed program were made for seven subjects. A 2-dB boost in overall gain was provided for one person at the initial fitting. Thus, eight participants obtained their final fitting at the initial session. One person required an adjustment for “hollowness of own voice” after 1 week of use, which resulted in an average 2-dB reduction in gain for high-input signals (G80) in the 1000- to 6000-Hz region. The remaining two participants requested more individual adjustments over the first 2-week period, summarized as follows: a 6-dB and a 9-dB boost in high-frequency gain for low-input signals (G50) with a smaller boost for high-input (G80) signals for the two participants, respectively, and minor adjustments (a boost for one and a reduction for the other participant) in the low-frequency gain. If changes were made, they were the same for both the OMNI and the DIR.

The participants were not informed of how the two programs differed. Rather, the first two memories were referred to as program 1 and program 2. The participants were told that the programs processed speech differently. They were instructed to switch between programs 1 and 2 whenever they encountered a new listening situation and to decide whether one setting seemed superior to the other. If so, they were to fill out a daily journal form describing the situation. The frequency responses of the OMNI and the DIR were equalized (using the “Max bass boost” option in the fitting software) to minimize the effect of the low-frequency roll-off (often perceived by the wearer as a difference in loud-
In accordance with the manufacturer's recommendations, the instruments were coupled to the participants' ears with custom lucite skeleton earmolds with #13 tubing, which, in many cases, were equipped with select-a-vents. The vent sizes were adjusted according to subjective feedback at the time of fitting or fine-tuning. Vent adjustments preceded electroacoustic (programming) changes for comments suggesting occlusion problems. The final vent sizes were generally small or medium. A pushbutton on the back of the instrument allows the wearer to switch between programs. An appropriate number of audible tones informed the user whether program 1, program 2, or program 3 had been activated. After the fitting, participants were oriented to the use of the new hearing aids.

Daily Journal

Over a 6-week period, each participant was asked to identify at least one listening situation daily in which one program (microphone mode) performed better than the other and to provide a detailed description of that situation using a daily journal form. A specific listening situation could be used only once during the 6 weeks, regardless of how often the participant encountered it. The daily journal consisted of two rating scales (described below) and 16 items, in a multiple-choice response format, describing the characteristics of the listening situation. Table 2 details the content of the daily journal questionnaire. The environmental characteristics of interest were those that are believed to influence hearing aid success, especially success with directional microphones, and included the characteristics of the talker(s) (e.g., type of voice, location, loudness of the voice), of the background noise (e.g., level, type, location), and of the listening space (e.g., room dimensions, reverberation). Space on the form was provided for additional comments and descriptions. The completed forms were reviewed by one of the investigators during weekly visits. Seven new descriptions per week were requested of each hearing aid user, with a minimum of three favoring each program. This latter requirement ensured that an adequate sample of situations favoring each microphone mode would be obtained. However, because no listening situation could be rated more than once and an equal number of ratings favoring each microphone mode was required, the daily journal ratings do not reflect the frequency of occurrence in...
Table 2  Questionnaire Items of the Daily Journal

<table>
<thead>
<tr>
<th>Primary Talker Variables</th>
<th>Background Noise Variables</th>
<th>Environmental Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Type of BN</td>
<td>Type of space</td>
</tr>
<tr>
<td>Adult male</td>
<td>Other people/how many</td>
<td>Building</td>
</tr>
<tr>
<td>Adult female</td>
<td>TV/radio/music</td>
<td>Car</td>
</tr>
<tr>
<td>Child (10 yr)</td>
<td>Machine or mechanical</td>
<td>Outdoors</td>
</tr>
<tr>
<td>Sounds of nature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Familiarity</td>
<td>Loudness (re primary talker)</td>
<td>Size (re average living room)</td>
</tr>
<tr>
<td>Yes</td>
<td>Much softer</td>
<td>Much smaller</td>
</tr>
<tr>
<td>No</td>
<td>Somewhat softer</td>
<td>Smaller</td>
</tr>
<tr>
<td></td>
<td>The same</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>Somewhat louder</td>
<td>Larger</td>
</tr>
<tr>
<td></td>
<td>Much louder</td>
<td>Very large</td>
</tr>
<tr>
<td>Distance (feet)</td>
<td>Constancy (time)</td>
<td>Flooring material</td>
</tr>
<tr>
<td>&lt; 3</td>
<td>Quite intermittent</td>
<td>Concrete/stone/tile</td>
</tr>
<tr>
<td>4–10</td>
<td>Intermittent</td>
<td>Wood</td>
</tr>
<tr>
<td>11–20</td>
<td>Almost constant</td>
<td>Partially carpeted</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>Constant</td>
<td>Fully carpeted</td>
</tr>
<tr>
<td>Location</td>
<td>Variability (loudness)</td>
<td>Wall material</td>
</tr>
<tr>
<td>Mostly in front</td>
<td>Quite variable</td>
<td>Concrete/stone/tile</td>
</tr>
<tr>
<td>Front and side</td>
<td>Somewhat variable</td>
<td>Mostly glass</td>
</tr>
<tr>
<td>Mostly to the side</td>
<td>Steady</td>
<td>Mostly drywall/wood</td>
</tr>
<tr>
<td>Mostly behind</td>
<td></td>
<td>Acoustic tile</td>
</tr>
<tr>
<td>Loudness (without your hearing aid)</td>
<td>Source location (re yourself)</td>
<td>Partially draped</td>
</tr>
<tr>
<td>Very soft</td>
<td>Mostly behind</td>
<td>Fully draped</td>
</tr>
<tr>
<td>Soft</td>
<td>Mostly in front</td>
<td>Ceiling material</td>
</tr>
<tr>
<td>Average</td>
<td>Mostly to the side</td>
<td>Concrete/stone/tile</td>
</tr>
<tr>
<td>Loud</td>
<td>All around</td>
<td>Dry wall</td>
</tr>
<tr>
<td>Very loud</td>
<td>Furnishings</td>
<td>Acoustic tile</td>
</tr>
<tr>
<td></td>
<td>Minimal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mostly hard tables and chairs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mostly upholstered furniture</td>
<td></td>
</tr>
</tbody>
</table>

BN = background noise.

everyday life of listening situations that favor one microphone mode over the other.

The two rating scales and the instructions for the daily journal entries are shown in Figure 3. Scale 1 was a 6-point scale indicating the degree of perceived difference between the two programs in terms of speech understanding (“a little better,” “better,” “much better”). Note that the scale did not provide an option for equal performance. Only listening situations in which the participant perceived a difference between the two programs could be included and reported.

Scale 2 was a percentage scale for estimating speech understanding when listening through program 1 and, separately, through program 2.

On the day of the hearing aid fitting, each participant was familiarized with the two rating scales and the questionnaire items. This familiarization included verbal explanations and demonstrations, laboratory tasks to judge differences between the two programs, and completion of at least one daily journal entry in a relatively noisy and large hospital lobby. These procedures provided direct experience for the participants and assurance that the hearing aid wearer was able to perceive differences between the OMNI and the DIR programs in specific listening conditions and to use the rating scales reliably. For the familiarization task in the laboratory, two test conditions were employed, using the Hearing Aid Research Laboratory recording (tracs 3–22) of the Speech Intelligibility Rating Test (Cox and McDaniel, 1989). In one condition, favoring the OMNI mode, the speech signal was presented through a loudspeaker located at 180 degrees azimuth and the interfering babble at 0 degrees. The other test condition favored the DIR, with the signal from a loudspeaker located at a 0 degree azimuth and speech babble at 180 degrees. For each test con-
Identify ONE specific listening situation in which you understand speech better with either Program #1 or Program #2 and complete this questionnaire. The PRIMARY TALKER is the person you most particularly wanted to understand. For each question, check the one answer that fits the best.

Listening situation: __________________________________________

Scale # 1:

Program #1 is much better than #2
Program #1 is a little better than #2
Program #1 is better than #2
Program #2 is much better than #2
Program #2 is better than #2
Program #2 is a little better than #2

In this ONE listening situation, about how much of the speech of the primary talker did you understand?

Scale # 2:

With Program #1:

0% 50% 100%

With Program #2:

0% 50% 100%

Figure 3 Directions for the use of the daily journal and the scales for rating preference and for estimating speech understanding for each program of the hearing aids.

dition, several sentences were presented while the listener switched between programs 1 and 2 until he or she indicated a preference using scale 1. Following this, estimates of speech understanding (scale 2) were obtained for one program at a time. After initial practice, the test conditions and the tasks were alternated and repeated until the participant provided at least three preference ratings that were in the same or within adjacent categories of the previous rating for each test condition. Large copies of the two scales were mounted on the wall in front of the listener, who responded verbally.

Participants quickly learned to complete the daily journal reliably, and the entire familiarization procedure took approximately 20 minutes. Completed daily journal entries were accepted from the first day of hearing aid fitting if the participant needed no further adjustments in the parameters of the hearing aids.

Laboratory Tests of Speech Recognition

At the end of the 6-week use of the Canta7 hearing aids, unaided and aided speech recognition was assessed using the Connected Speech
Test (CST) (Cox et al, 1987, 1988) at two different presentation levels and levels of background noise. They were the moderate (60/0, two-talker babble) and high (75/+2, six-talker babble) noise conditions used in an earlier study of directional BZ5 hearing aids (Walden et al, 2000). The presentation levels and signal-to-noise ratios were selected to yield midrange scores and to be representative of relatively difficult listening situations that are encountered in everyday listening (Walden, 1997). Detailed descriptions of the test conditions are available in Walden and colleagues (2000). Briefly, the CST sentences were presented through a loudspeaker positioned at a 0 degree azimuth and correlated speech babble from three loudspeakers at 90, 180, and 270 degrees. Both the test sentences and the competing babble were digitized and presented online to the listeners. The order of the hearing aid conditions (unaided, OMNI-aided, DIR-aided) and test conditions (moderate, high) was randomized. A minor change from the earlier protocol was to increase the number of test passages from four to six for each condition. Hence, the CST scores for the present study are based on 150 key words for each test condition.

Subjective Ratings

At the end of the 6 weeks of hearing aid use, the Profile of Hearing Aid Benefit (PHAB; Cox and Gilmore, 1990; Cox and Rivera, 1992) was used to measure hearing aid performance in the field. The performance of each program was assessed by a single administration of the PHAB using a side-by-side response format; that is, the two response columns, normally marked “without my hearing aid” and “with my hearing aid,” were relabeled program 1 and program 2. Finally, participants were asked to estimate the percentage of time that they used the hearing aids in program 1 and program 2 over the 6 weeks.

RESULTS

Connected Speech Test

The results of the speech recognition tests for the two aided conditions are reported as rationalized arcsine units (rau) (Studebaker, 1985). The CST scores for the omnidirectional and directional microphones for the two test conditions are shown in Figure 4. The error bars indicate 1 SD. Paired t-tests indicated that the mean DIR-aided score was significantly higher than the mean OMNI-aided score for both test conditions (p < .001). The directional advantage (DIR minus OMNI) for individual participants is given in the first two columns of Table 3 and reveals substantial individual variability. These results are consistent with the earlier clinical trial of a hearing aid with fixed hypercardioid directional pattern (Walden et al, 2000) and confirm that the directional microphones provided significantly better speech recognition than the omnidirectional microphone under these laboratory listening conditions. Further, given that these speech recognition measures were administered at the end of the 6-week trial, these data provide indirect evidence that the performance of the dual microphones did not drift significantly during the trial use period.

Profile of Hearing Aid Benefit

The PHAB results for the four scales are summarized as frequency of success ratings (i.e., 100 minus the frequency of problems) in Figure 5. That is, the higher the bar, the better the performance. Again, the error bars indicate 1 SD. It appears that the DIR-aided ratings were slightly better than the OMNI-aided ratings for the first three scales. However, the differences were small and not statistically significant. The p values of the paired t-tests for the four scales comparing the OMNI with the DIR ranged from 0.09 to 0.67. Notably, the slight performance advantage for the DIR mode was observed for both the quiet and the background noise scales, suggesting that the different signal processing by the two microphones was not a major factor in the ratings.

Taken together, the CST and PHAB results are consistent with the earlier findings of Walden and colleagues (2000) and again suggest that,
Table 3  Microphone Advantage in Laboratory and Field Data for Each Participant

<table>
<thead>
<tr>
<th>Subject</th>
<th>60/0 Condition</th>
<th>75/2 Condition</th>
<th>OMNI (n = 60)</th>
<th>DIR (n = 155)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.4</td>
<td>37.1</td>
<td>26.4</td>
<td>29.7</td>
</tr>
<tr>
<td>2</td>
<td>23.1</td>
<td>14.1</td>
<td>16.7</td>
<td>14.7</td>
</tr>
<tr>
<td>3</td>
<td>32.3</td>
<td>22.8</td>
<td>6.3</td>
<td>18.7</td>
</tr>
<tr>
<td>4</td>
<td>53.3</td>
<td>58.6</td>
<td>20.0</td>
<td>8.7</td>
</tr>
<tr>
<td>5</td>
<td>9.4</td>
<td>18.6</td>
<td>10.0</td>
<td>23.3</td>
</tr>
<tr>
<td>6</td>
<td>33.4</td>
<td>48.5</td>
<td>40.0</td>
<td>50.0</td>
</tr>
<tr>
<td>7</td>
<td>16.0</td>
<td>22.0</td>
<td>0</td>
<td>13.3</td>
</tr>
<tr>
<td>8</td>
<td>32.0</td>
<td>28.8</td>
<td>15.0</td>
<td>6.3</td>
</tr>
<tr>
<td>9</td>
<td>0.6</td>
<td>16.8</td>
<td>0</td>
<td>7.5</td>
</tr>
<tr>
<td>10</td>
<td>16.3</td>
<td>22.5</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>11</td>
<td>16.5</td>
<td>39.4</td>
<td>2.5</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Directional advantage in the laboratory is the directional mode (DIR)-aided minus the omnidirectional mode (OMNI)-aided Connected Speech Test (CST) scores.

The microphone advantage in the field is the preferred mode minus nonpreferred mode percentage estimate of speech understanding (scale 2 of the daily journal).

typically, people do not report directional advantages in everyday life, although substantial directional benefit is observed in laboratory measures.

Daily Journal

All 11 participants reported difficulty finding listening situations where they could perceive a difference between the two programs, particularly after the first week or two of hearing aid use. Their general impression was that both programs performed equally well in most situations. In addition, situations favoring the OMNI were more difficult to identify than those favoring the DIR for many participants. As a result, the number and the distribution of the journal entries fell short of our goal of obtaining daily descriptions from every participant that were equally distributed between the two microphone modes. In addition, it became evident during the weekly clinic visits and reviews of the journals that most participants tended to use the “a little better” rating category somewhat unreliably. In varying words, they often indicated that they were not quite sure that the two programs were different, yet provided a description with the “a little better” rating for one of the two microphone modes to fulfill their assigned task. This ambivalence was clearly reflected in the estimates of speech understanding (see below).

The number of journal entries ranged from 23 to 44 per participant across the 11 participants (mean = 34.7, SD = 6.8). A total of 382 descriptions were obtained. Of these, 155 (40.6%) situations favored the OMNI and 227 (59.4%) favored the DIR. Among the 11 participants, 6 provided a relatively even number of entries for the two microphone modes. Four participants identified and described more situations that favored the DIR than situations in favor of the OMNI, and one participant described situations mostly in favor of the OMNI. Across the two microphone modes, ratings of “much better” were used only 4.2 percent of the time, “better” 52.1 percent of the time, and “a little better” 43.7 percent of the time. Because of the questionable reliability of the participants’ use of the “a little better” category, the data analyses of the daily journal entries focused on descriptions of the listening situations associated with the two more definitive rating categories (“better” and “much better”) for each microphone mode. That is, descriptions of listening situations associated with the least certain preference category (“a little better”) for each microphone mode were omitted from the data analyses. Of the total of the 215 descriptions within these four remaining categories, 60 (27.9%) favored the OMNI and 155 (72.1%) favored the DIR.

The effect of omitting the “a little better” rating category was not uniform across the 11 participants. The first data column of Table 4 lists the full data set and the second column shows the number of preference ratings obtained from each participant for the “better” and “much better” rating categories. It is clear that the preference ratings by participants 5, 6, 7, 9, and 10.
were mostly in the "a little better" category. These five participants, therefore, seldom encountered listening situations in their daily lives where there was a clear advantage for either microphone mode and, therefore, contributed relatively few of the 215 situation descriptions analyzed.

Each data set (OMNI and DIR) was analyzed separately according to each of the environmental variables described in Table 2. Thus, for example, the percentages of the 60 omnidirectional listening situations were calculated where the primary talker was located in front, to the side, front and side, and back of the listener. Similarly, these percentages were calculated for the 155 listening situations favoring the directional microphones. (The number of omnidirectional situations and directional situations varied slightly across the analyses because the daily journal entries were not always complete.) Interpretation of the raw percentages is complicated by the inequality of the frequencies with which primary talkers are encountered in each of these four locations in everyday listening situations. For example, most participants infrequently communicated with a talker located behind them. However, by comparing the relative distribution of these four categories between the two data sets, we may gain insight into whether this talker variable influenced microphone preference. This was accomplished by chi-square analyses.

**Primary Talker Variables**

Among the primary talker variables (see Table 2), location of the primary talker appeared to have the greatest influence on microphone preference (chi-square = 17.98, p = .001). Figure 6 shows the percentage distribution of the OMNI and the DIR preferences according to the location of the primary talker. Overall, listening situations in which the talker was located in the front were identified most frequently for both microphone modes, whereas situations where the talker was located in back were relatively rare. Within this general pattern, however, a DIR preference was more likely to occur in talker-in-front situations and an OMNI preference more likely to occur in talker-in-back situations.

Three additional primary talker variables may have influenced microphone choice, that is, the chi-square statistic approached statistical significance for familiarity (chi-square = 2.91, p = .09), distance (chi-square = 5.42, p = .14), and loudness (chi-square = 5.92, p = .11). A DIR preference appeared more likely to occur when the talker was familiar, at distances of 10 feet or less, and spoke at soft and average levels. In contrast, an OMNI preference appeared more likely to occur when the talker was unfamiliar, at distances greater than 10 feet, and spoke at very soft or loud levels.

**Background Noise Variables**

The chi-square analyses suggested that two of these variables—the presence versus absence (chi-square = 4.08, p = .04) and the type of background noise (chi-square = 11.47, p = .009)—significantly influenced microphone preference. Figure 7 shows the distributions for the two microphone modes according to presence and absence of background noise. Although background noise was present in most situations where a preference for either microphone mode was perceived, it was more likely to be present in situations in which the DIR was preferred and absent in situations where the OMNI was preferred.
The source or type of background noise also appeared to influence microphone preference (chi-square = 11.47, p = .009). Figure 8 shows the distribution for this variable. People and the sounds of nature were more likely to be the sources of interfering noise in situations where the OMNI was favored, whereas television, radio, music, and machine noises (including fans, traffic, and restaurant clatter) were more likely to be in the background when the DIR was preferred. Interactions with other variables, such as relative loudness or spatial separation of the primary talker and the background noise, may have influenced this outcome.

Environmental Variables

The chi-square analyses of the environmental variables (i.e., characteristics of the listening space) suggested that the type of space (chi-square = 7.88, p < .05) significantly influenced microphone preference. Figure 9 summarizes the distributions for the two microphone modes for this variable. Most communication situations in which a difference between the microphone modes was perceived took place in buildings. (This is most likely because the data were collected from January to March, when people in this geographic area spend most of their time indoors.) However, when the distributions of the two microphone configurations across space types were compared, an OMNI preference was more likely to occur in cars and outdoors, whereas preference for the DIR was more likely to occur in buildings. Again, this finding may reflect an interaction with other variables such as location of the primary talker and a presence or absence of background noise.

The size of space in which communication took place (outdoors was excluded from this analysis) also may have had an effect on microphone preference; that is, the chi-square approached significance (chi square = 7.73, p = .10). These results are summarized in Figure 10. The OMNI was more likely to be preferred in smaller rooms and the DIR in rooms of average size (relative to an average living room). Neither microphone type appeared to be more likely to be preferred in large indoor spaces.

Estimates of Speech Understanding

In addition to the microphone preference rating and description of the listening situation, the daily journal required an estimate of speech understanding for each program (i.e., microphone type). For the 60 situations in which the omnidirectional microphone was preferred, the average speech understanding ratings for the omnidirectional and directional microphone modes were 93.7 percent (SD = 5.6) and 76.4 percent (SD = 18.4), respectively. Hence, participants estimated that the omnidirectional microphone provided an average of 17.4 percentage points better speech understanding than the directional microphones in situations where the omni-
directional microphone was preferred. For the 155 situations in which the directional microphone was preferred, the average speech understanding rating was 96.1 percent (SD = 8.0) for the directional microphones and 82.8 percent (SD = 14.9) for the omnidirectional microphone. Thus, in situations where the directional microphones were preferred, they were judged to provide an average of 13.3 percent better speech understanding than the omnidirectional microphone. The data for the individual participants are shown in the second set of columns of Table 3 ("mean microphone advantage... "). Individual variability is apparent, with some participants reporting substantially better speech understanding with the omnidirectional or the directional microphones in everyday listening situations, whereas others failed to detect such differences despite expressing a preference for one or the other microphone mode.

OMNI and DIR Use Pattern

Recall that at the end of the study the participants were asked to indicate the percentage of time they used each microphone mode. On average, participants reported using the OMNI 32.7 percent of the time (SD = 28.1, range = 5–90%) and the DIR 67.3 percent of the time (SD = 28.1, range = 10–95). Table 5 shows the use pattern for each participant (the last set of columns). Seven participants used the DIR much more than the OMNI (3, 4, 5, 6, 7, 8, 11), two used OMNI much more than DIR (1, 10), and for the remaining two (2, 9), the use of the two microphone modes was fairly evenly divided.

DISCUSSION

The primary purpose of this study was to identify characteristics of everyday listening situations that influence user preferences for omnidirectional or directional hearing aid microphones. The results suggest that four general characteristics of listening situations—location of the primary talker, presence or absence of background noise, type of background noise, and type of space in which communication takes place—significantly influence microphone choice. Listening situations in which the talker is behind the listener and background noise is absent increase the likelihood that the omnidirectional microphone will be preferred. In situations in which noise is present, the likelihood that the omnidirectional mode will be preferred is increased if the noise source is other people talking or sounds of nature. In addition, the likelihood that the omnidirectional mode will be preferred is increased in smaller environmental spaces, particularly in cars, as well as outdoors. A preference for directional microphones is more likely if the talker is located in front of the listener, and if background noise is present and its sources are television, radio, music, machines, or general clatter. The likelihood that directional microphones will be preferred is also increased in average-sized rooms.

In general, the influence of environmental factors on microphone preference observed in this study is consistent with that reported by Kuk (1996) in a retrospective survey of satisfied wearers of a switchable dual-microphone omnidirectional/directional hearing aid. It should be recalled that participants reported only on environmental variables that were included in the daily journal. The environmental characteristics assessed in this study are those that are believed to influence hearing aid success, especially suc-
cess with directional microphones. However, it must be recognized that this list of environmental variables may not be exhaustive.

It seems likely that the influence of room size is indirect and reflects an interaction with other variables, such as the presence or absence of background noise, the distance between the talker and listener, the location of the signal, and the amount of reverberation. Recall that the likelihood of an omnidirectional preference was increased in very small rooms and outdoors, whereas the likelihood of a directional microphone preference was increased in average-sized rooms. In very large indoor spaces, neither microphone preference was increased in average-sized rooms. In very large indoor spaces, neither microphone preference was increased in average-sized rooms, whereas the likelihood of a directional microphone preference was increased in very small rooms and outdoors, and the amount of reverberation. Recall that the presence or absence of background noise, the distance between the talker and listener, the location of the signal, and the amount of reverberation all influenced the preferences. However, it seems likely that the largest influence on preference was room size. Generally, the large spaces described by the participants in the phone mode emerged as superior. Given the large number of listeners, it is perhaps surprising that the location of the background noise did not appear to exert a comparable influence. Directional microphones tended to be preferred when background noise was present, but the location of the noise did not seem critical to this preference. The ability of directional microphones to improve the signal-to-noise ratio in a noisy listening situation depends on some spatial separation of the sources of the signal and noise in the environment. Theoretically, they should work best when the location of the noise coincides with a null in the polar pattern provided by the device. Conventional directional hearing aids provide a fixed polar pattern and, therefore, are maximally effective only when the noise source is located in the direction of a null, usually directly behind or to each side of the listener. The Canta7, however, features adaptive directionality, which places the null in the direction of the most intense noise source located in the environment. This should provide greater flexibility in terms of the location of the noise, for optimal performance and may partially account for the nonsignificant influence of noise location in this study. However, the directional microphones were as likely to be selected when the noise was located in front of the listener as when it was in any other location. The most frequently reported listening situations (favoring either microphone mode) were those in which the background noise seemed to be all around. In the presence of diffuse noise, the Canta7 places the null in the direction where the signal is loudest to the sides or behind the listener. In situations of equal loudness across the rear plane, the hearing aid defaults to a hypercardioid pattern. When competing noise is coming from many different directions outdoors, there is little reason to expect that omnidirectional and directional microphones would provide markedly different performance.

Perhaps the most notable finding of this study was that all participants found it difficult to identify listening situations in their everyday lives in which one microphone mode clearly outperformed the other. Rather, the two microphone modes generally seemed to perform equally well in most listening situations. When a preference was perceived, it was often small, in terms of both preference ratings and estimates of speech understanding. This was especially true for 5 of
the 11 participants, who could not often detect reliable differences between the two microphone modes (see Table 4). It appears, therefore, that in most everyday listening situations, hearing aid users do not notice substantial performance differences between omnidirectional and directional microphones. Although the generalizability of this finding is limited by the small sample size, it is consistent with the results of Walden and colleagues (2000), who observed minimal differences between omnidirectional and directional microphone performance in everyday listening among 40 subjects. The results of the present study are also consistent with the findings of the companion study, a clinical survey of 112 patients fitted with switchable omnidirectional/directional hearing aids (Cord et al., 2002).

Of the patients who reported wearing their hearing aids regularly, approximately one-third reported leaving their hearing aids set in one microphone mode or the other, usually the omnidirectional setting. That is to say, although they had the directional microphone option available, they did not regularly use it.

Although all participants had difficulty identifying everyday listening situations in which one microphone mode provided distinctly superior performance to the other, a majority of the participants identified more situations favoring the DIR than the OMNI. Mueller and colleagues (1983) observed a similar pattern in a field trial of a single-microphone directional hearing aid that featured switchable omnidirectional modes through a slider located on the device. A similar finding in this study is particularly notable because the participants were repeatedly requested throughout the 6-week trial to describe an equal number of situations favoring each program. It is tempting to conclude, therefore, that most patients fitted with switchable omnidirectional/directional hearing aids encounter more listening situations in which the directional microphone is superior to the omnidirectional microphone than vice versa. However, this may not necessarily be the case. Recall that every listening situation reported in the daily journals had to be unique, that is, no situation could be repeated, and, further, that an equal number of descriptions favoring each microphone mode was requested. Hence, these data do not necessarily reflect the frequency with which situations favoring one microphone mode or the other are encountered in daily living. It is informative to note, in this regard, that the patients surveyed by Cord and colleagues (2002) reported that they encountered everyday listening situations in which the omnidirectional mode provided superior performance significantly more often than situations in which the directional mode was judged to be superior. Further, the data of the current study suggest that some patients find it easier to identify listening situations in which the omnidirectional mode is preferred. Nevertheless, the pattern that emerges is that, for the majority of the patients, directional microphones perform about as well as an omnidirectional microphone in most everyday listening situations (with some specific exceptions; see above). However, when the two microphone modes perform differently in a particular listening situation, it is more likely that the directional mode is the better of the two.

This general view is consistent with the use pattern that was reported by the participants at the end of the study. Despite not knowing the specific difference between program 1 and program 2, the participants reported using their hearing aids in the directional mode, on average, approximately 67 percent of the time. Given that it was easier to identify listening situations in which the directional mode was superior, it may have seemed a useful strategy to leave their hearing aids in that mode. However, setting their hearing aids in the directional mode as a strategy for fulfilling the requirements of this study probably does not totally explain why the directional mode was used more, on average, than the omnidirectional mode. At the conclusion of the study, the differences between the two program settings were described to the participants. Three to 6 months following their participation in the study, they were again interviewed. Notably, the use patterns remained essentially the same across individual participants, and, on average, they reported using the DIR mode 59 percent of the time.

The greater overall use of the directional mode reported in this study differs substantially from that observed in the clinical survey of Cord and colleagues (2002) in which patients reported using the directional microphone setting only 22 percent of the time. One major difference between the studies was the hearing aids used. The current study used only one hearing aid model, which featured adaptive directionality and equalized frequency responses between the two microphone modes. In the survey of Cord and colleagues (2002), patients had been wearing switchable omnidirectional/directional hearing aids of various manufacturer makes and models, all providing a fixed directional polar pattern. It is possible that the Canta7 provides superior directional signal processing to the instruments.
included in the study of Cord and colleagues, resulting in greater reliance on the directional mode in everyday listening.

Several other factors may have influenced the use pattern observed in the survey of Cord and colleagues (2002) and, thereby, the discrepancy of their data with the findings of this study. In clinical practice, patients typically are instructed to use the omnidirectional setting as the primary mode and to switch into the directional option only in certain types of listening situations. Presumably, these instructions create a bias toward use of the omnidirectional microphone. Equalization of the frequency responses between the two microphone modes, type of circuit (WDRC), and lack of user-operated volume controls probably affected the use pattern in the present study, whereas these aspects varied across the clinic patients surveyed in the study of Cord and colleagues. Further studies are needed to assess the influence of these factors. It is interesting to note that Preves and colleagues (1999) conducted a field trial of omnidirectional/directional hearing aids in which participants were blinded, as in the present study, to the specific differences between the two programs. More than half of their participants reported that, if they could have only one microphone option, they would prefer the directional mode.

In clinical hearing aid fittings, the omnidirectional option is most often the default memory. This is reflected in the “first choice” option in many manufacturers' software programs that place the omnidirectional mode into the default memory and use specific labels, such as “restaurant,” for the other memories, which include the directional feature, implying that the directional mode is for specific situations only. This also may bias clinic patients toward use of the omnidirectional mode. The results of the present study, however, do not provide strong support for the notion that the default setting, which was counterbalanced between the two microphone modes, biases wearers of switchable omnidirectional/directional hearing aids to use the default setting. The six participants for whom the default setting was the omnidirectional mode reported that they used the directional microphones an average of 61 percent of the time, whereas the five participants for whom the default setting was the directional mode reported an average use of the directional microphones of 75 percent of the time. A t-test comparing use of the directional mode for these two groups was not significant (t = 0.86, p = .41) because of large within-group variance and the small sample size.

**Clinical Implications**

As with any clinical study, the generalizability of the results to clinical practice are limited by the experimental design, including the use of only one hearing aid model, the dependent measures obtained, and a relatively small sample of participants. Although there is no way to determine that the Canta7 provided an optimal fit to every participant, most commented that they seemed to hear better with the new hearing aids than with their old ones. The limitations due to sampling were compounded by the decision to eliminate the “a little better” rating category. As a result, relatively few ratings from nearly half of the participants were included in the final analyses.

The results of this study suggest that laboratory tests of speech recognition to evaluate the directional advantage overestimate the benefit provided by directional microphones in everyday listening. Clinicians, therefore, should be cautious about creating unrealistic expectations of the benefits of directional microphones in everyday living through demonstrations of their effectiveness in an audiometric test booth. It appears that omnidirectional and directional microphones would provide comparable performance in most listening situations encountered in daily living. Clearly, directional microphone technology works as designed, as shown by the substantial performance advantages it provides over omnidirectional microphones under certain laboratory conditions. However, it appears that most everyday listening situations do not approximate these “ideal” laboratory conditions sufficiently to realize comparable benefit in everyday living. Nevertheless, some patients will encounter some listening situations in which noticeably superior performance will be obtained from directional microphones. It is important, therefore, that clinicians carefully interview potential candidates for switchable omnidirectional/directional hearing aids to assess the specific listening situations in which they are experiencing difficulty. Additionally, it is important that patients understand the characteristics of listening situations that influence success with directional hearing aids so that they can assess the potential of this option to improve speech understanding when they encounter difficult listening situations. Further, with this knowledge, they may be able to alter listening situations to optimize success with directional microphones.

Finally, given that the omnidirectional and directional microphones provided comparable performance in most listening situations and
that the majority of the participants found it easier to identify situations in which the directional was preferable to the omnidirectional mode than the reverse, clinicians might consider making the directional mode the default program when programming switchable omnidirectional/directional hearing aids for patients. If hearing aids are programmed in this manner, patients would be advised of the characteristics of listening situations in which they should switch into the omnidirectional microphone but would generally leave their hearing aids set in the directional mode. However, such a fitting strategy is unlikely to be optimal for every patient. There appear to be substantial individual differences in the success obtained in everyday listening from directional microphones. These differences across patients most likely reflect differences in the characteristics of the listening situations that are frequently encountered in their everyday lives. Such variation in success again points to the importance of a thorough prefitting assessment of the characteristics of the listening situations in which the patient is experiencing difficulty.

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