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Evaluation of a Second-Order Directional Microphone Hearing Aid: II. Self-Report Outcomes

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Abstract

This clinical trial was undertaken to evaluate the subjective benefit obtained from hearing aids employing automatic switching second-order adaptive directional microphone technology, used in conjunction with digital noise reduction, as compared to a fixed directional microphone or omnidirectional microphone response with the same digital noise reduction. Data were collected for 49 participants across two sites. Both new and experienced hearing aid users were fit bilaterally with behind-the-ear hearing aids using the NAL-NL1 (National Acoustics Laboratory—Nonlinear version 1) prescriptive method with manufacturer default settings for various signal processing (e.g., noise reduction, compression parameters, etc.). During ten days of hearing aid use, participants responded to daily journal questions. Subjective ratings for each of the three hearing aid responses (omnidirectional, automatic-adaptive directional, and automatic-fixed directional) were similar. Overall preference for a microphone condition was equally distributed between no preference, omnidirectional, and automatic adaptive and/or fixed directional.

Key Words: Adaptive-directional microphone, directional, fixed-directional microphone, hearing aid, hearing aid preferences, second-order microphone, subjective ratings

Abbreviations: DI = directivity index; DNR = digital noise reduction

Sumario

Este estudio clínico fue llevado a cabo para evaluar el beneficio subjetivo obtenido por el uso de auxiliares auditivos que utilizan tecnología adaptable de segundo de orden con interruptor automático para micrófonos direccionales, usados en conjunto con reducción digital del ruido, en comparación con la respuesta de un micrófono direccional fijo o de un micrófono omnidireccional, con la misma reducción digital del ruido. Se recolectaron datos de 49 sujetos en dos contextos. Se les adaptaron curvetas retroauriculares a usuarios nuevos y con experiencia en el uso de auxiliares auditivos usando el método de prescripción del Laboratorio Nacional de Acústica – Versión no lineal 1 (NAL-NL1), con la programación original del fabricante en varios parámetros de procesamiento de la señal (p.e., reducción del ruido, compresión, etc.). Los participantes respondieron a las preguntas de una bitácora diaria, durante diez días de uso de los auxiliares auditivos. Los juicios subjetivos para cada una de las respuestas (omnidireccional, direccional adaptable automático y direccional fijo automático) fueron similares. La preferencia global para un

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micrófono se distribuyó igualmente entre los criterios de: sin preferencia, omni-direccional, y direccional automático adaptable y/o fijo.

Palabras Clave: Micrófono direccional adaptable, direccional, micrófono direccional fijo; auxiliar auditivo, preferencia de auxiliar auditivo, micrófono de segundo orden, juicios subjetivos

Abreviaturas: DI = Indice de direccionalidaad; DNR = reducción digital del ruido

Individuals with sensorineural hearing loss typically have a significant problem listening in situations with poor signal to noise ratios, more so than people with normal hearing (Davis, 1947; Plomp, 1978; Killion, 1997). Hearing aids using standard omnidirectional microphone signal processing can provide increased audibility but are not effective in improving the signal-to-noise ratio (SNR) in everyday listening environments (Van Tasell, 1993). In fact, Ricketts (2000) found that some omnidirectional hearing aids make speech understanding in these noisy conditions worse than in the unaided condition for individuals with mild-moderate sensorineural hearing loss listening to relatively high speech input levels.

A variety of signal processing schemes have been attempted to alleviate difficulty communicating in noise. The two most common schemes relate to some type of digital noise reduction (DNR) and the application of directional microphone technology. Published laboratory studies consistently show that DNR does not improve speech intelligibility (Ricketts and Dhar, 1999; Walden et al, 2000; Alcantara et al, 2003; Ricketts and Hornsby, 2005). Research concerning listeners' *preference* for DNR, however, has shown conflicting findings. For example, Alcantara et al (2003) did not find evidence for improved listening effort or comfort, or for sound clarity or quality, when testing a noise reduction system. This is consistent with the work of Walden et al (2000), who reported that adding the DNR feature to directional technology did not result in greater listener preference than directional technology alone, although the *combined* effect was superior to omnidirectional. In contrast, Ricketts and Hornsby (2005) recently demonstrated a significant preference for DNR when used with either omnidirectional or directional technology. In all three studies, laboratory testing was conducted to simulate possible real-world conditions.

The use of hearing aids with directional microphones has been suggested as a more promising solution than DNR for difficulty understanding in noise because of the potential enhancement in signal-to-noise ratio provided by the microphone arrangement (see Ricketts and Mueller, 1999, for a review). Directional microphone hearing aids have been available since the 1960s. Recent technologic advances have included smaller custom products with directional options, a second-order design, automatic switching between omnidirectional and directional, selection of different polar plots, and most recently, the provision of different polar responses implemented in an adaptive manner in response to incoming signals from different azimuths.

Over the years, there has been considerable research with directional hearing aids, and the results from laboratory and controlled clinical studies have been mostly positive and encouraging. The effectiveness of these instruments in realistic backgrounds, however, has been challenged (Cord et al, 2002; Walden et al, 2003; Cord et al, 2004). Mueller and Hawkins (1990) reviewed several real-world studies of directional hearing aids conducted with a traditional single-microphone design. In one of these studies, Mueller et al (1983) used a hearing aid that could be switched from directional to omnidirectional. They found that for most listening conditions, a large percentage of subjects (e.g., 40–50%) could not tell the difference between the two microphone settings, although when a preference existed, it favored the directional microphone (except for the listening in quiet condition).

In a similar study conducted more recently with dual-microphone technology, Cord et al (2002) found that individuals fit with hearing aids with switchable directional/omnidirectional microphone settings used the directional setting only one-quarter of the time. Despite the limited use, however, the individuals reported fewer communication problems when using directional technology. The authors concluded that directional hearing aids implemented in the real world require environmental manipulation in that the user must perceive the need for enhanced listening in noise and then must position him- or herself appropriately while using the directional setting.

Surr et al (2002) investigated characteristics of everyday listening situations that are likely to influence user preferences for either omnidirectional or directional microphones. Eleven individuals were fit with hearing aids with omnidirectional and directional programs without knowing the difference between programs. Participants were asked to use both settings in each new communication situation and track which setting they preferred in a diary. All subjects reported difficulty identifying listening situations where they could perceive a difference. The diary analysis revealed that location of the signal, presence or absence of noise, type of noise, and environmental characteristics (listener space) dictated whether the participants chose the directional setting over the omnidirectional setting. These data are consistent with the findings of Cord et al (2002) indicating that in order for the directional mode to be perceived as beneficial, the listener must be able to manipulate the listening environment and understand the function of the directional microphone (e.g., the signal must be in front, the noise must be spatially separated from the signal source, the room must not be highly reverberant). Similar findings were reported by Ricketts et al (2003).

With the introduction of second-order (three-microphone) directional hearing aids, and the resultant potential for higher directivity capability, one might expect better performance by the hearing aid user in real-world settings as compared to first-order directional hearing aids. In addition, when this type of microphone is implemented with adaptive polar plots, which change characteristics in certain listening environments, even greater benefit without the need for such careful environmental manipulation might be expected.

Recently, an automatic/adaptive directional design with a second-order microphone has been introduced into a wearable hearing aid (see Powers and Hammaker, 2004, for a review). In this design, the characteristics of the polar pattern are under control of the signal processing algorithm and are continually adjusted according to the properties of the environmental sounds. Only hearing aids with two or more microphones can implement this adaptive option, as the evolving polar pattern depends on the summed outputs of the separate microphone signals. The noise source is suppressed by the resultant low sensitivity of the microphone in one or more directions (Soede et al, 1993).

The magnitude of improvement with directional microphones depends on the source(s) and distance of the primary signal and the noise as well as the amount of reverberation in the environment (e.g., Hawkins and Yacullo, 1984; Novick et al, 2001; Ricketts and Hornsby, 2003). Most of the research to date has evaluated *fixed* one- or two-microphone designs where the polar pattern achieved by the microphone characteristics is held constant. There has been little research with second-order adaptive directional microphones and what does exist focuses on objective benefit in a laboratory setting (e.g., Bentler et al, 2004; Ricketts et al, 2005). Research has not been conducted studying real-world subjective preference for the adaptive polar pattern design as compared with the fixed polar pattern response. Considering the potential for improved directivity with the second-order microphone as compared to first-order microphones and the automatic *and* adaptive nature of the directionality that potentially could alleviate the need for environmental manipulation by the hearing aid user, it was of interest to access preferences for an omnidirectional, second-order fixed directional, and second-order adaptive directional hearing aid in everyday listening situations in a group of hearing-impaired individuals.

Therefore, the purpose of this investigation was to answer the following questions:

1. Do participants' self-report evaluations reveal that a second-order adaptive directional hearing aid is superior to an omnidirectional or second-order fixed directional hearing aid?
2. On average, do participants prefer one of the three directional microphone configurations for most everyday listening situations?

3. Do specific listening situations predict which of three directional microphone configurations will be perceived as better?

METHODS

The detailed methods of this clinical trial are provided in a companion paper (Bentler et al) in this issue. The methods section below provides an overview of specific details of the research protocol in order to provide a basis for interpreting the findings.

Participants

Forty-nine individuals participated in this clinical trial (25 from the University of Iowa site and 24 from the University of Pittsburgh site). The subject pool consisted of 22 females and 27 males. The age range of the participants was 27 to 85 years, and the mean age was 62.1 (SD = 13.7). There were no significant differences in age between the University of Pittsburgh and University of Iowa participants. All participants met the following criteria: (1) downward-sloping bilateral sensorineural (A/B [air/bone] gap <10 dB) hearing loss; (2) hearing levels no better than 20 dB HL (American National Standards Institute, 1996) at 500 Hz and no worse than 75 dB HL at 3000 Hz; and (3) hearing symmetry within 15–20 dB.

There were 18 (37%) new hearing aid users and 31 (63%) experienced hearing aid users. The participants were considered new users of amplification if they reported less than 60 days of hearing aid use within the past 12 months, and an experienced user if they had at least six months of regular use in the past 12 months. Many of the participants from the experienced group were users of digital and/or directional technology.

Participants were recruited from the population of individuals seen routinely in the two clinical sites. Participants were paid $200 at completion of the study.

Procedures

Following informed consent, audiometric evaluations were conducted for all participants. Pure-tone thresholds were obtained for the frequencies of 250, 500, 1000, 2000, 4000, and 8000 Hz, using a Grason-Stadler Instruments GSI-16 audiometer (re: ANSI S3.6, 1996 [American National Standards Institute, 1996]). Pure-tone signals were presented through ER-3A insert earphones. Thresholds ranged from 20 dB HL to 75 dB HL from 500 to 3000 Hz with bilateral symmetry within 15–20 dB for any given frequency (refer to Figure 1 for the average pure-tone thresholds). There were no significant differences in thresholds at the .01 level between the University of Pittsburgh and the University of Iowa participants. Ear impressions were taken bilaterally, and acrylic earmolds with pressure vents were obtained for all participants.

Hearing Aids

The Siemens Triano3^{TM} behind-the-ear hearing aids were used to implement the second-order adaptive directional microphone in this investigation. The polar patterns that can be achieved with the second-order design are considerably more complex than a first-order design and the resultant directivity index (DI) theoretically higher (see Powers and Hammaker, 2002, for a review). At the time of this research, the hearing aids could be programmed to be omnidirectional, or to automatically switch between omnidirectional and directional. In the automatic switching setting, either a fixed polar pattern (hypercardioid) or adaptive polar pattern

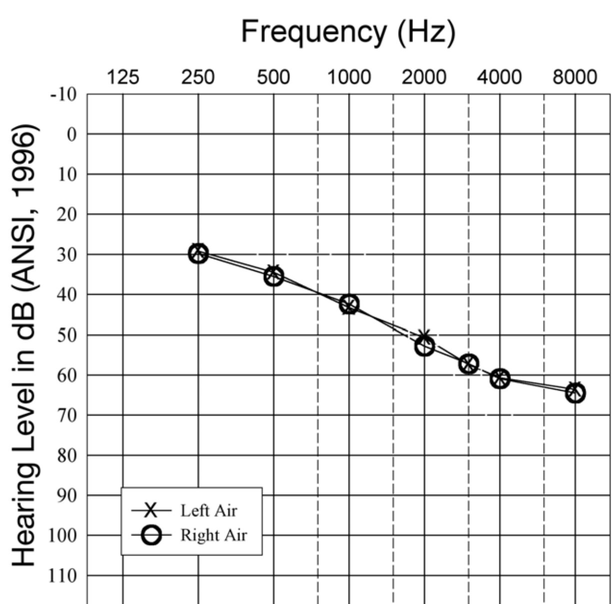

Figure 1. Average pure-tone thresholds for participants.

could be selected. When set to automatic switching, the algorithm for determining switching from omnidirectional to directional was based on the spectral content of the signal (e.g., speech versus noise), the duration of the signal, and the overall level of the signal (>54–57 dB SPL). This investigation required a hearing aid that could achieve these three listening conditions within one hearing aid so participants would be blind to the differences in hearing aid memories while they were able to switch memories between days without needing to wear a different hearing aid.

The hearing aids were programmed to the manufacturer-implemented NAL-NL1 (National Acoustics Laboratory—Nonlinear version 1) fitting strategy (Dillon, 1999), and the real-ear response was verified with probe-microphone measures (Audioscan Verifit at University of Pittsburgh; Frye Electronics 6500 at University of Iowa). The two directional conditions were programmed identically including equalization of the low-frequency response. Refer to the companion manuscript (Bentler et al, in this issue) for measurement outcomes. Since it was important to the design of the study to establish that the hearing aids were indeed functioning as directional during the field trial, we conducted our own DI measurements of the instruments before and after experimental testing. All laboratory testing for the directional conditions was conducted with the automatic switching activated, which indirectly served as verification of the function of this feature. Hence, we can be reasonably confident that when these participants used the hearing aids in the field trial in the automatic switching mode, and the characteristic of input signal triggered the switch to directional, the hearing aids were performing appropriately.

Two different types of DNR and adaptive feedback are implemented in these hearing aids and were activated for all real-world testing. Specific information regarding the design and programming of these features can be found in Bentler et al (in this issue). Since most advanced technology hearing aids are employing some type of DNR and adaptive feedback, the default settings for these features were used in this investigation and were active in all three listening conditions (omnidirectional, fixed directional, and adaptive directional). If preferences had been collected with the DNR off, the clinical utility of the data would be in question, since most clinicians use the default "DNR-On" setting of the instrument when programming the hearing aids for the patient. It was not the goal of the field portion of this investigation to assess the impact of the microphone conditions as separate from the DNR employed in this instrument.

Self-Report Outcomes

Participants were tested with a variety of speech understanding in noise tests (described by Bentler et al, in this issue) for both the omnidirectional and directional conditions, with noise reduction "on" and "off." These were laboratory activities, and participants did not wear the hearing aids outside of the clinic between these visits.

At the end of the objective tests, the hearing aids were set to provide four different listening programs. Program 1 was omnidirectional; Program 2 was automatic/adaptive directional (condition used during first portion of field trial); Program 3 was automatic/fixed directional (hypercardioid polar pattern); and Program 4 was set to telecoil. Other than Program 4, participants were blinded as to the specifics of the memories. The participants were told that they were trying three new signal processing strategies. Digital noise reduction was set to maximum in each program, and adaptive feedback management was turned on in each program.

Participants were provided with a diary (Appendix 1) that served as a wearing schedule and a questionnaire specifically designed for this research. One hearing aid program was assigned for each of two days creating a wearing schedule for six days (two days for each of three hearing aid programs). The order of program use (1–3) was counterbalanced between participants to avoid order effects and to guarantee that one program would not be worn only on a weekend, which might have different communication demands than weekdays. The programs were changed via a button on the hearing aids. As the button was pushed, the hearing aids presented a number of audible beeps corresponding to the program that was selected. All participants were instructed in the use and care of the hearing aids. Ample time was allotted for participants to practice switching programs and to review the diary so they were confident in which hearing aid memory to use each day.

Following each day of hearing aid use, the participant responded to six statements (see Appendix 1): (1) Speech was more clear than usual today; (2) Noise was not as bothersome today; (3) I wore my hearing aids longer than usual today; (4) I was less tired than usual by later afternoon; (5) I could hear important sounds in my environment at comfortable levels; and (6) Sounds coming from different directions sounded normal. Statements were rated on an 11-point scale from 0 to 10 with 0 indicating complete agreement with the statement and 10 indicating complete disagreement.

From Days 7–10, participants were allowed to switch between the three listening programs and responded to a different set of diary questions (Appendix 2). These questions included: (1) I could tell the difference between the three programs on my hearing aid (yes or no); (2) Circle the program that you used most during the past four days (Program 1, 2, 3). The second part of the diary questions (for Days 7–10) included eight statements that could be circled related to any of the three programs. The statement begins "I found Program #1 (or #2 or #3) was better than the other programs when (circle all that apply)" and then ends with one of eight listening conditions (see Appendix 2). The conditions included understanding in a quiet environment, understanding in a little noise, understanding in a lot of noise, when tired, wanting to be comfortable, wanting to know where sound is coming from, hearing quiet sounds, and understanding in a variety of different listening situations.

In this type of real-world evaluation, the listening environments encountered by the participants cannot be controlled. Therefore, one cannot report the amount of time the hearing aid functioned in specific ways except for in the omnidirectional setting. In the omnidirectional setting, the hearing aid is known to function with an omnidirectional microphone response regardless of the environment. In the two automatic settings, the sound environment around the individuals will dictate whether the hearing aid is functioning in the omnidirectional condition or the directional condition. Further, in the adaptive directional condition, the sound environment also will dictate what polar pattern is responding. Neither the listening environment nor the microphone changes can be controlled when evaluating these systems in the real world. However, a large group of participants and several days of use should ensure that, as a group, these individuals are exposed to a representative sample of listening environments and that the hearing aids have the opportunity to function with a variety of polar responses.

Data Analysis

Data were entered into two identical spreadsheet templates at the University of Iowa and the University of Pittsburgh. These Microsoft Excel spreadsheets were combined and data were taken directly from these spreadsheets for analysis. Means and standard deviations of participants' responses were calculated for all diary questions. In addition, the number of participants responding to certain items was tallied in order to determine the percent of the group responding in a certain fashion.

RESULTS

This result section addresses the three research questions:

1. Do participants' self-report evaluations reveal that a second-order adaptive directional hearing aid is superior to an omnidirectional or second-order fixed directional hearing aid?

Figure 2 presents the participants' overall ratings related to the three hearing aid programs that they were able to switch between over six days of use. These represent data from the six days when participants were asked to use only one hearing aid program per day. The participants spent two days each in the omnidirectional-only microphone condition, the automatic/fixed directional condition, and the automatic/adaptive directional microphone condition. In general, mean performance showed moderate agreement with the six positive statements. There was no significant difference, however, across the six different statements, and the agreement for specific questions did not vary as a function of microphone condition.

2. On average, do participants use one of the three directional microphone configurations for most everyday listening situations?

Figure 3 presents the number of participants who reported the greatest use of each microphone condition after using the hearing aids for ten days. Approximately one-third of the participants could not tell a difference between conditions, one-third used the omnidirectional condition most, and one-third used an automatic/directional condition (either fixed or adaptive) most.

3. Do specific listening situations predict which of three microphone configurations will be perceived as better?

Figure 4 reveals the number of participants who preferred a particular microphone mode (omnidirectional, adaptive directional, or fixed directional) in each of eight listening situations. The questions in this part of the investigation do not relate to how often a program was used but whether it was perceived as superior in specific listening situations even if they occurred rarely. Overall, the omnidirectional microphone setting was considered best for the majority of situations by the majority of participants when considering the three microphone conditions separately. Very few participants found that there was a "best" microphone configuration when they were "tired."

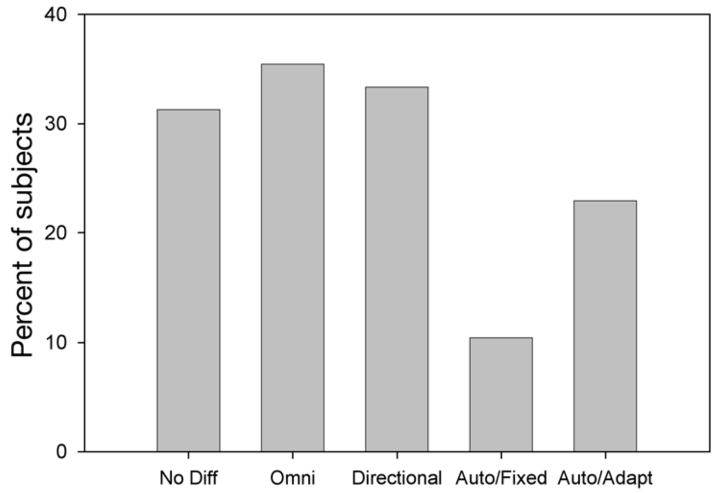

Figure 3. Percent of subjects reporting "Program Used Most" during Days 7–10 of the at-home trial. Approximately one-third of the subjects reported not being able to tell the difference between the programs provided. The third bar (Directional) represents the combination of the final two bars.

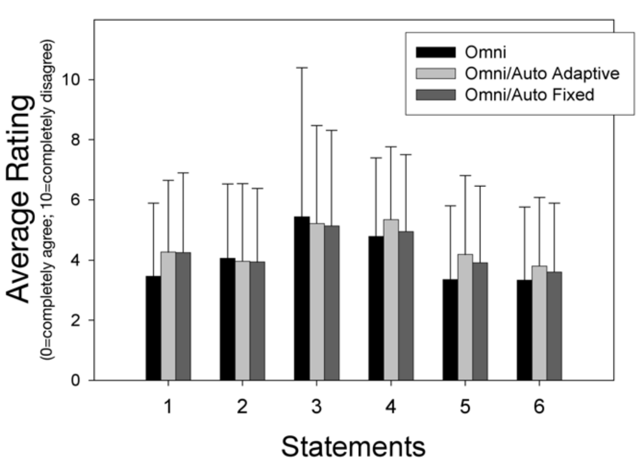

Figure 2. Average ratings for six diary statements that participants responded to over a six-day period (using each hearing aid condition for two days). (1) Speech was more clear than usual today; (2) Noise was not as bothersome today; (3) I wore my hearing aids longer than usual today; (4) I was less tired than usual by late afternoon; (5) I could hear important sounds in my environment at comfortable levels; (6) Sounds coming from different directions sounded normal.

The situations included in this questionnaire did not differentiate between the auto/adaptive and auto/fixed directional microphone setting; therefore, the results for the two directional microphone conditions were combined and are replotted in Figure 5. When considering the directional microphone conditions together, the majority of participants preferred to use Program 2 or 3 (either directional setting) for some listening situations. The leading situations were "when in a variety of listening situations" and "when in a lot of noise."

DISCUSSION

The purpose of this research was to derive subjective evaluations for a new design of directional technology that had received little real-world evaluation: a second-order directional microphone that uses automatic switching between omnidirectional and directional, with fixed and adaptive directional polar pattern options. Mean ratings for the six items of the microphone condition questionnaire (Appendix 1) indicate remarkably similar results for the three

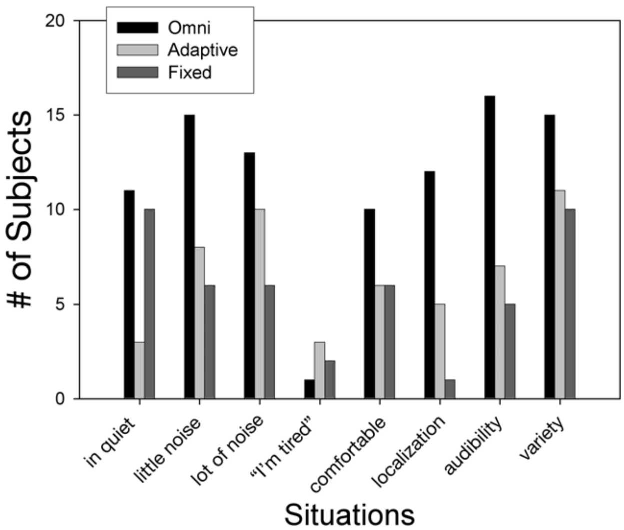

Figure 4. The program that was found most useful in each of the eight listening situations (understanding in quiet, understanding in a little noise, understanding in a lot of noise, listening when tired, wanting to be comfortable, wanting to know where sound is coming from, hearing quiet sounds, communicating in a variety of different listening situations.)

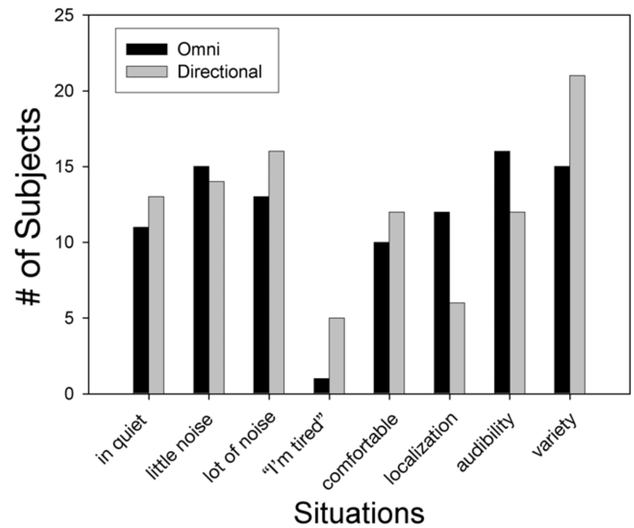

Figure 5. The program (omnidirectional vs. directional configurations combined) that was found most useful in each of the eight listening situations.

microphone conditions (Figure 2) studied (omnidirectional, automatic adaptive directional, and automatic fixed directional). This could be because there actually was no difference in the real world, or because the items/questions were too general (e.g., "noise was not as bothersome today"). For example, in a similar study, Ricketts et al (2003) reported that there was no significant advantage for directional technology in the real world based on the BN (background noise) subscale of the APHAB (Abbreviated Profile of Hearing Aid Benefit) (Cox and Alexander, 1995). Yet when these same participants completed a separate questionnaire containing questions geared toward situations when a directional advantage would be expected, a significant advantage was observed. The questions used in this study were not specifically geared toward the potential directional advantage, as we did not specify distance from talker, location of talker, amount of reverberation, and so forth.

It may be important to consider that in the present study, digital noise reduction was set to "maximum" for *both* the omnidirectional and automatic directional conditions. For these experimental instruments, the maximum DNR setting could result in a gain reduction of 12 to 16 dB in some channels; an input signal that would have triggered the switch to directional also would have activated DNR. It is possible, therefore, that the magnitude of the DNR masked the directional effect for some of the listening conditions included on the questionnaire.

Given that this is one of the first field studies of the effectiveness of automatic switching directional technology, it is worth pointing out that the automatic directional settings were not rated *any worse* than omnidirectional (See Figure 2). That is, there was no difference between omnidirectional and automatic/directional for "speech was as clear," "important sounds in the environment were at comfortable levels," and "sounds coming from different directions sounded normal." While in the automatic mode, the hearing aids did function as omnidirectional part of the time, however, because the activation level for directional was ~55 dB SPL. Other than quiet, or speech-in-quiet, we can assume that these hearing aids were in the directional mode for most listening situations. In the automatic/adaptive mode, the polar pattern will default to hypercardioid whenever there is not a dominant background noise from a specific azimuth. For many listening environments, therefore, the automatic/fixed and the automatic/adaptive settings would have resulted in the same output.

When asked to indicate which program

was used most after being allowed to switch between the omnidirectional only, automatic/fixed directional, and automatic/adaptive directional conditions for several days, one-third of the participants could not tell the difference between programs and were not able, therefore, to vote; one-third reported using the omnidirectional program the most, and one third reported using one of the two directional conditions the most (Figure 3). Recall that the subjects were blinded as to the actual condition programmed into each memory; they only reported memory number. Walden et al (2003) asked a group of participants to indicate how much of the time they preferred their omnidirectional and directional setting. Participants indicated that they preferred the omnidirectional setting approximately one-third of the time, the directional setting one-third of the time, and had no preference one-third of the time. Similarly, Cord et al (2002) reported that individuals using a first-order fixed directional microphone used the directional setting one-fourth of the time. The question asked in the present study was different from the other two studies in that individuals could not pick the amount of time they would like each setting but, rather, had to pick the best overall setting for their daily communication. Regardless of how the question was asked, the division of preference is similar.

Eight listening situations (understanding in a quiet environment, understanding in a little noise, understanding in a lot of noise, listening when tired, wanting to be comfortable, wanting to know where sound is coming from, hearing quiet sounds, and communication in a variety of listening situations) were presented to the participants during four days of hearing aid use where they could choose the "best" hearing aid listening program. The results in Figure 4 illustrated that the set of listening situations as presented in this study did not differentiate the two directional microphone conditions. When the directional microphone conditions were combined (Figure 5), the "best" hearing aid programs (omnidirectional *versus* directional) are fairly evenly divided between participants (e.g., 15 individuals preferred omnidirectional listening in a little noise and 14 preferred directional listening). It is reassuring that approximately equal numbers of participants preferred omnidirectional or directional listening in the quiet situations since all of the hearing aid programs would have automatically switched the omnidirectional response in quiet. Twice as many participants found that they could localize better in the omnidirectional listening condition, which would be consistent with the potential for reduced cues in the directional setting. A few more individuals preferred the directional microphone settings in "a lot of noise" and in "a variety of listening situations," which would be expected since these may be the two most noisy and demanding situations listed in the set of eight statements. In general, the addition of a second-order microphone as implemented in this study does not appear to have greatly improved the contrast between everyday listening situations with these different microphone conditions. These findings agree with previous real-world studies with directional technology (Mueller et al 1983; Cord et al, 2002; Surr et al, 2002; Walden et al, 2003). For example, Mueller et al (1983) reported that many of their subjects could not tell the difference between a first-order directional and omnidirectional setting. Thirty-three percent of the individuals in the current investigation also reported that they could not tell the difference between programs.

Surr et al (2002) and Walden et al (2004) investigated the characteristics of the listening environment that would predict hearing aid microphone preference. Both studies reported that a directional mode was preferred when background noise was present and the signal source was located in front of and relatively near the listener. Both groups of investigators suggest that this information can be used in counseling patients about appropriate use of a switchable directional microphone. The characteristics of the sound environment were neither controlled nor documented in this investigation because the goal was to have individuals functioning in their real-world environments. In particular, the eight statements used to determine preferences for the microphone conditions were not detailed in terms of where the noise was, how loud the signal was, and so forth, and this may have contributed to the lack of differentiation between microphone conditions.

The agreement of these data with data from previous investigations of mode preference (Mueller et al, 1983; Cord et al, 2002; Surr et al, 2002; Walden et al, 2003) suggests that the current implementation of a second-order automatic adaptive directional microphone with DNR does not create a listening condition that is readily differentiated from, nor preferred over, the fixed-directional or omnidirectional listening conditions. On the other hand, because perceived performance in the second-order automatic adaptive directional condition appears to be no worse if not better than the other two microphone conditions, clinicians may choose to implement this technology in order to reduce the need for training the patient when to switch microphone responses as reported by Surr et al (2002) and Walden et al (2004) with first-order fixed directional microphones.

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APPENDIX 1.

The following is an example page of the daily diary provided to subjects. The Program to be listened through was indicated in the blank space on each of the six pages (six days). Identical statements were evaluated each day. For Days 7–10, the subject could choose between programs and then rated statements for each program at the end of the Day 10 (these statements are provided in Appendix 2).

Day 1 (or 2–6): Please keep your hearing aid on Program _____ throughout the day today. At the end of the day, please circle the area of the "Completely Agree" to "Completely Disagree" ruler that indicates how closely you agree with the statement. For example, if it was a sunny day today and the statement was "Today was a sunny day." You would circle completely agree.

1. Speech was more clear than usual today.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

2. Noise was not as bothersome today.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

3. I wore my hearing aids longer than usual today.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

4. I was less tired than usual by late afternoon.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

5. I could hear important sounds in my environment at comfortable levels.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

6. Sounds coming from different directions sounded normal.

   Completely Agree Completely Disagree

   \————\————\————\————\————\————\————\

APPENDIX 2.

The following is the page from the diary that the subject completed after Days 7–10 of hearing aid use. During these days the subject was instructed to use whatever memory they found most useful in each situation they encountered. The subject responded to the statements at the end of Day 10 for each hearing aid memory.

Days 7–10. For the next four days, you are free to listen using only one Program all day or using different Programs if you want to switch between them depending on what you are listening to. You should choose whatever seems best for you. Please set both hearing aids to the same program. At the end of the fourth day (Day 10), please answer the questions below.

1. I could tell the difference between the 3 Programs on my hearing aid.
   No (If you have circled No, you do not need to respond to the questions below)
   Yes (If you have circled Yes, please answer the questions below)
2. Circle the Program that you used the most during the past 4 days.
3. I found Program #1 was better than the other programs when (circle all that apply)
   a. I never use Program 1
   b. I'm trying to understand in a quiet environment
   c. I'm trying to understand in a little noise
   d. I'm trying to understand in a lot of noise
   e. I'm tired
   f. I want to be comfortable
   g. I want to be sure to know where sound is coming from
   h. I need to hear quiet sounds
   i. I am in a variety of different listening situations
4. I found Program #2 was better than the other programs when (circle all that apply)
   a. I never use Program 1
   b. I'm trying to understand in a quiet environment
   c. I'm trying to understand in a little noise
   d. I'm trying to understand in a lot of noise
   e. I'm tired
   f. I want to be comfortable
   g. I want to be sure to know where sound is coming from
   h. I need to hear quiet sounds
   i. I am in a variety of different listening situations
5. I found Program #3 was better than the other programs when (circle all that apply)
   a. I never use Program 1
   b. I'm trying to understand in a quiet environment
   c. I'm trying to understand in a little noise
   d. I'm trying to understand in a lot of noise
   e. I'm tired
   f. I want to be comfortable
   g. I want to be sure to know where sound is coming from
   h. I need to hear quiet sounds
   i. I am in a variety of different listening situations