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Effect of Age on Directional Microphone Hearing Aid Benefit and Preference

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Abstract

Background: Despite the recognition that the directional microphone hearing aid (DMHA) is an important intervention aimed at helping older hearing-impaired adults understand speech in noisy environments, there is little evidence that older listeners can actually benefit from directional processing.

Purpose: The objective of this study was to determine if older and younger adults can obtain and perceive comparable benefit afforded by DMHAs.

Study Sample: Twenty-four hearing-impaired adults aged 36 through 79 yr were fit with switchable-microphone hearing aids and tested in the laboratory and the field.

Data Collection and Analysis: In the laboratory, the listeners' directional benefit and preferences for microphone modes (directional vs. omnidirectional) were assessed using various speech-recognition-in-noise tests. In the four-week field trial, a paired-comparison technique and paper-and-pencil journals were used to determine the benefit provided by directional processing. The effects of age on directional benefit/preference were analyzed using generalized linear models with controlling for the effect of hearing loss.

Results: The results revealed that age did not have a significant effect on directional benefit and preference as measured in the laboratory. However, the field data showed that older age was significantly associated with a lower preference for the directional mode.

Conclusion: These results indicate that although listeners of different ages may obtain and perceive comparable benefit from DMHAs in laboratory testing, older users tend to perceive less benefit than do younger users in the real world. The implications of these findings are discussed.

Key Words: Aging, directional, hearing aids

Abbreviations: AV = audiovisual; CST = Connected Speech Test; DIR = directional; DMHA = directional microphone hearing aid; GLM = generalized linear model; HINT = Hearing in Noise Test; HFA = high-frequency average of hearing loss; NAL-NL1 = National Acoustics Laboratory–Nonlinear Version 1; OMNI = omnidirectional; REAR = real-ear aided response; SNR = signal-to-noise ratio

INTRODUCTION

One of the most common complaints of persons with hearing loss is difficulty in understanding speech amid background noise (e.g., Takahashi et al, 2007). Compared to younger listeners, elderly listeners face greater hearing challenges in noisy environments because they exhibit poorer speech-perception performance in such settings than do younger listeners. This diminished ability is currently presumed to involve factors ranging from age-related changes in peripheral hearing sensitivity (Humes et al, 1994; Schneider et al, 2000; Murphy et al, 2006) and auditory temporal processing (Fitzgibbons and Gordon-Salant, 1996; Snell et al, 2002; Souza and Boike, 2006) to changes in central cognitive abilities (Pichora-Fuller

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et al, 1995; Tun et al, 2002; Lunner and Sundewall-Thorén, 2007).

Hearing aid amplification is the primary intervention for sensorineural hearing loss and its related psychosocial consequences (Mulrow et al, 1990; Chisolm et al, 2007; Takahashi et al, 2007). However, traditional hearing aids amplify speech as well as background noise and can thus provide only a limited improvement in speech perception in noise. Therefore, it is not surprising that the difficulty in comprehending speech in noisy environments is reported as the primary reason for hearing-impaired adults to stop using hearing aids (Takahashi et al, 2007). Apparently, in order to increase hearing aid use/satisfaction and provide greater quality of life to the older population, improving speech perception in noise with the use of a hearing aid is critical.

One technology shown to improve speech perception in noise is the directional microphone. Unlike traditional omnidirectional microphone hearing aids, directional microphone hearing aids (DMHA) can amplify speech signals while reducing noise signals. Specifically, if DMHA users can place the talker in front of them and position other environmental noise in their rear hemisphere, DMHAs can improve signal-to-noise ratio (SNR) and enhance speech intelligibility because DMHAs are more sensitive to on-axis signals (i.e., signals coming from the front) and less sensitive to off-axis signals (i.e., signals coming from the rear hemisphere). In most modern hearing aids, the microphone can be switched between the directional (DIR) and the omnidirectional (OMNI) modes either manually or automatically. With the manually switchable system, hearing aid users have to identify the speech/noise configuration and choose the appropriate microphone mode. An automatic system can automatically switch the microphone mode according to decision rules and acoustic characteristics of the environment (e.g., Olson et al, 2004).

In the laboratory, the benefit afforded by DMHAs is often referred to as directional benefit, calculated as the difference in speech-recognition performance between the DIR and the OMNI modes of the same hearing aid. A large body of literature has consistently shown that DMHAs can improve speech perception in noise (Valente et al, 1995; Ricketts, 2000b; Ricketts et al, 2003; Bentler, Egge, et al, 2004; Bentler, Palmer, and Dittberner, 2004; Bentler, Tubbs, et al, 2004; Ricketts et al, 2005; Bentler et al, 2006). Laboratory data have also shown that listeners with severe hearing loss (Ricketts and Hornsby, 2006) and children (Gravel et al, 1999; Kuk et al, 1999) are benefited by directional hearing aids. Moreover, DMHAs may still improve speech intelligibility even when the noise is speech or speechlike signals (Hornsby and Ricketts, 2007).

Because DMHAs can improve speech perception in noisy environments, and because older listeners have greater difficulty understanding speech in such settings than do young listeners, fitting hearing aids with directional microphones to older hearing-impaired adults is regarded as a reasonable intervention (Kricos, 2006). However, to date, there is little evidence showing that older listeners actually benefit from DMHAs. While, on one hand, considerable benefit has been observed in several studies using laboratory testing involving older participants (Surr et al, 2002; Walden et al, 2005), on the other hand, a number of researchers have observed that the directional microphone does not work well for older listeners in the real world (Yueh et al, 2001; Souza, 2004). Souza (2004) suggests that older listeners may obtain less benefit from the DMHA because of their inability to recognize environments in which switching to the DIR mode might result in the greatest advantage. She also suggests that automatic directional systems could be helpful for these listeners. In one study using a questionnaire to investigate microphone mode preference in daily listening environments (Kuk, 1996), 29 of 89 older participants reported that they left their DMHAs in the same microphone mode (usually the default mode: OMNI) all the time. However, the investigator suggested that age seemed not to be a limiting factor in determining the benefit of the DMHA in the field because three of seven younger participants did the same. It should be noted, though, that in the Kuk study the sample size of the younger listeners was much smaller than that of the older listeners and the degree of hearing loss was not controlled when examining the effect of age on DMHA benefit.

My previous study, which was designed to investigate the effect of visual cues on directional microphone benefit and preference (Wu and Bentler, 2010a, 2010b), provided an opportunity to systematically determine if the use of the DMHA can provide real benefit to older listeners. In that study, both younger and older adults with similar degrees of hearing loss were recruited to examine the efficacy and effectiveness of the DMHA in the laboratory and in the field. In addition, the participants in that study were well trained to recognize the type of environment in which the directional microphone is most effective. The specific aims of the present study were to determine (1) whether both older and younger listeners could obtain comparable directional benefit in a laboratory environment involving the speech-front/noise-rear configuration and (2) whether, after training, older and younger listeners could perceive comparable benefit from DMHAs in the real world with a similar speech/noise configuration.

METHOD

Participants

In order to provide a basis for interpreting the findings, this section provides an abbreviated summary of the methods used in the larger study. (For the details, see Wu and Bentler, 2010a, 2010b). Twenty-four adults (10 males, 14 females) were recruited and served as subjects. Participants met the following criteria: They had to (1) be between the ages of 20 and 80 yr, (2) have bilateral downward-sloping sensorineural hearing loss, (3) have a hearing loss no better than 20 dB HL at 500 Hz and no worse than 75 dB HL at 3 kHz (re: American National Standards Institute, 2004), (4) have a hearing symmetry of within 15 dB for all test frequencies, (5) have an absence of cognitive disorder (screened by the Mini-Mental State Examination [Folstein et al, 1975; Crum et al, 1993], scoring higher than 28 out of 30 points), and (6) be a native speaker of English. Participants' ages ranged from 36 to 79 yr with a mean of 64 yr. Half of the participants were younger than 65 yr (inclusive; i.e., Young Group), and half of the participants were older than 65 yr (i.e., Old Group). The participants' ages, gender, mean hearing threshold across the left and right ears, and average high-frequency hearing loss (HFA; averaged across 1000, 2000, and 4000 Hz) are summarized in Table 1. The mean hearing thresholds of the Young Group and the Old Group were very close, except for thresholds at 4000 and 8000 Hz (Fig. 1). Independent t-tests indicated that the differences at 4000 and 8000 Hz between younger and older participants were significant ($t = 2.14$ and $p = .04$ for 4000 Hz; $t = 4.87$ and $p < .001$ for 8000 Hz), while their thresholds at other frequencies were not statistically different. Eight of the participants had no previous hearing aid experience, while 16 subjects were experienced users. A participant was considered an experienced user if he or she had used hearing aids more than 4 hr per day in the previous year. Five of the experienced users' own hearing aids were equipped with directional microphones. However, none of them reported regular use of the directional mode. The participants were not informed of any aspect of microphone technology.

Hearing Aids and Fitting Procedures

Participants were fitted bilaterally with Starkey Destiny 1200 in-the-ear hearing aids. This device is a fully digital, multimemory hearing aid that can be programmed to the OMNI or DIR modes. The directional

Table 1. Participants' Age, Gender, Mean Hearing Thresholds, and High-Frequency Average of Hearing Loss (HFA)

Group	Subject No.	Age	Gender	Mean Hearing Threshold (dB HL) 250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	HFA (dB HL)	Gain Compensation	Venting
Young Group	01	36	M	40	48	60	65	70	68	65	1	2
	02	44	F	30	35	30	35	40	40	35	1	2
	03	48	F	38	43	53	60	60	53	58	1 → 2*	2
	04	51	M	23	30	35	63	70	63	56	1 → 2*	2
	05	56	F	53	55	53	53	63	60	56	1	2
	06	58	M	25	43	58	63	65	65	62	1	2
	07	59	F	28	33	50	50	53	23	51	2	2
	08	60	F	38	43	45	55	63	63	54	1	2
	09	61	F	18	30	73	73	63	60	69	2	2
	10	63	M	30	33	40	38	43	43	40	1	3
	11	64	F	30	33	33	45	45	48	41	2	2
	12	65	F	25	35	45	58	60	68	54	2	2
Old Group	13	68	F	38	48	60	50	45	65	52	1	1
	14	68	F	28	38	45	45	60	85	50	2	2
	15	70	M	33	55	50	43	95	85	63	1	1
	16	70	M	33	53	70	73	63	75	68	1	1
	17	71	M	43	48	53	70	80	75	68	1	1
	18	71	F	48	55	58	70	65	75	64	1	1
	19	72	M	33	28	35	53	85	85	58	2	3
	20	72	M	25	40	55	70	80	80	68	1	1
	21	73	F	43	43	48	60	53	60	53	1	2
	22	74	F	38	30	45	60	68	85	58	1	2
	23	79	F	30	43	63	65	65	73	64	1	2
	24	79	M	20	30	38	48	65	80	50	2	2

Note: Participants no older than 65 yr old (inclusive) are classified as the "Young Group"; participants older than 65 yr old are classified as the "Old Group." Gain compensation group: 1 = gain equalized; 2 = gain nonequalized. Venting group: 1 = 1 mm or smaller; 2 = between 1 mm and 2 mm (inclusive); 3 = larger than 2 mm.

*Two participants changed from gain compensation group 1 to group 2 because they noticed the internal noise of the directional microphone in the middle of the study.

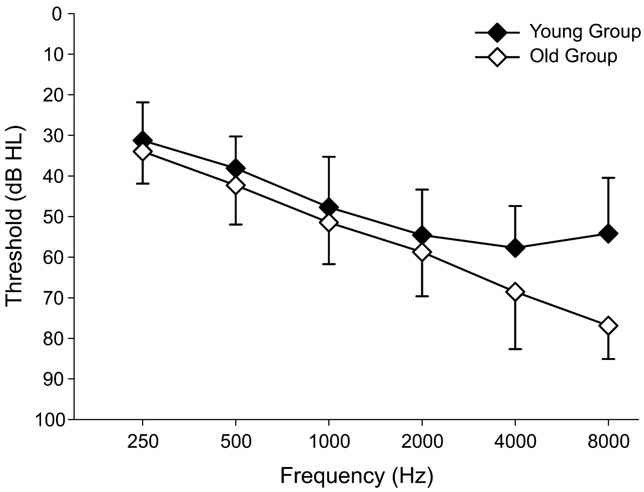

Figure 1. Mean hearing thresholds for younger and older participants. The error bars indicate one standard deviation.

microphone has a fixed, hypercardioid polar pattern. During the study, the OMNI and DIR modes were programmed into the two memories of the hearing aid and were accessed by pushing a button on the faceplate. The memory was identified by the number of "beeps" heard after pushing the button. The automatic switch feature of the microphone system, the volume control wheel, and the noise-reduction algorithm were disabled throughout the study.

The hearing aids were first programmed using the "best fit" option of the fitting software. The real-ear aided responses (REARs) were then measured by a real-ear hearing aid analyzer (Verifit) by presenting speech signals from 0 degrees azimuth and were adjusted to match the National Acoustics Laboratory–Nonlinear Version 1 (NAL-NL1) targets (Dillon, 1999). For all participants, the gains of the two microphone modes were initially equalized (i.e., the low-frequency roll-off of directional processing was fully compensated; gain option #1). If the participants reported that they heard the hissing internal noise inherent to the directional microphone, three more options of low-frequency gain compensation were applied stepwise to lower the noise level: reducing the low-frequency gains of both microphone modes with the gain equalized (gain option #2), applying the "partial compensation" option in the DIR mode (gain option #3), and applying the "no compensation" option in the DIR mode (gain option #4). The gain options were applied until the listeners considered the internal noise to be the same in both microphone modes. After applying each option, the REAR measure was repeated. If the difference in the REAR between microphone modes was found to be larger than 3 dB, or if the REARs deviated from the NAL-NL1 targets by 3 dB in any frequency bands, the option was not applied even though the internal noise was still audible. The use of various low-frequency gains would make the results of the study more clinically applicable because the manufacturer did not suggest fully compensating the gain of the DIR mode when the internal noise is audible. The averaged REAR of each microphone mode for a 70 dB SPL input and the averaged NAL-NL1 targets are shown in Figure 2.

In order to reduce the occlusion effect and make the results of the study more clinically applicable, the vent size was determined according to the degree of low-frequency hearing loss. Specifically, for a hearing loss of no more than 30 dB HL at 500 Hz, a vent size of 2 mm was used. The vent was reduced by 0.5 mm for every 10 dB increase in hearing loss at 500 Hz (Valente et al, 2006). A larger vent was used when the listener continued to report the occlusion effect. To examine if different gain compensations and vent sizes impacted the results, in the later statistical analyses participants were classified into two gain compensation groups (gain equalized: gain options #1 and 2; gain nonequalized: gain options #3 and 4) and three vent size groups (1 mm or smaller, between 1 and 2 mm, larger than 2 mm). The grouping is summarized in Table 1.

Laboratory-Based Measures

Two tests measuring speech recognition in noise were administered to assess directional benefit: the Hearing in Noise Test (HINT [Nilsson et al, 1994]) and the audiovisual (AV) version of the Connected Speech Test (CST [Cox et al, 1987; Cox et al, 1988, 1989]). The HINT is an adaptive-SNR speech-recognition measure that eliminates ceiling and floor performance effects. The listener was instructed to repeat a block of 20 sentences in a background of speech-shaped noise. All blocks were

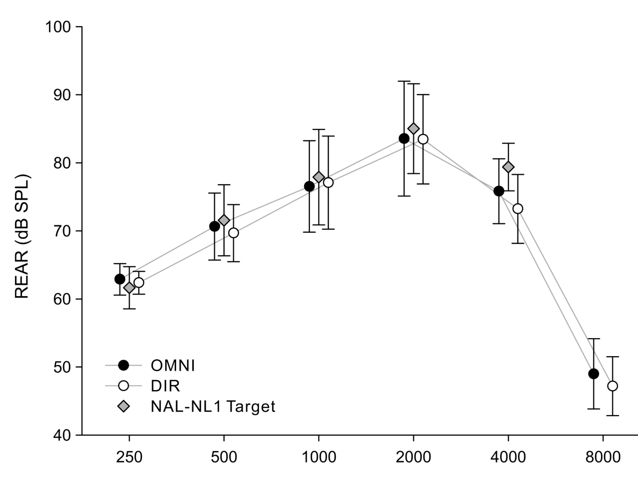

Figure 2. Mean real-ear aided responses (REARs) of the omnidirectional (OMNI) and the directional (DIR) modes averaged for the right and left ear fittings. Solid squares represent mean National Acoustics Laboratory–Nonlinear Version 1(NAL-NL1) targets. The error bars indicate one standard deviation.

randomly selected without replacement. The speech-shaped random noise was fixed at 65 dBA. The speech level was adjusted adaptively depending on the listener's responses. The speech presentation level across sentences 5 through 20 was then averaged to obtain the threshold at which the listener achieved 50% correct performance. The threshold was measured in the DIR and the OMNI modes.

The AV CST is a fixed-SNR (nonadaptive) test designed to simulate everyday conversations in which contextual cues are usually available. This AV speech-recognition test was chosen because visual cues (i.e., lip reading) are usually available in environments in which the directional microphone is most effective (i.e., the talker is in front of the listener). The listener was instructed to repeat sentences heard amid multiple-talker babble from a collection of passages about common topics. Each passage consisted of nine or ten sentences. The scoring was based on the number of key words repeated by the listener out of 25 key words per passage. As in the larger study (Wu and Bentler, 2010a), the listener's aided sentence recognition in noise was measured in 24 conditions: 2 microphone modes (DIR and OMNI) × 2 presentations (AV and auditory only) × 6 SNRs (–10 to +10 dB in 4 dB steps). One pair of CST passages was presented and scored in each condition. The SNR conditions consisted of a fixed 65 dBA speech with various babble levels. The recorded talker's face was presented from a 17 in LCD monitor. The size of the face on the screen was slightly smaller than a life-size face. The test orders of microphone mode, presentation, and SNR were counterbalanced across participants. Because the effect of visual cues has been shown to play an important role in directional benefit measures (Wu and Bentler, 2010a, 2010b), and because the SNRs of typical real-world noisy environments are between –1 to +4 dB (Pearsons et al, 1976), only the data obtained using visual cues at SNRs of –2, +2, and +6 dB were employed in this study to determine the effect of age on directional benefit.

The CST was also used to assess the listener's preference for directional processing. A modified version of the comparison technique described by Walden and colleagues (2005) was used. Specifically, the participant was asked to listen to CST sentences in babble using the DIR or OMNI modes alternatively and then indicate his or her preferred microphone mode based on the perceived speech intelligibility. The microphone mode was controlled by an examiner using a programming interface (HiPRO) and the fitting software. For each preference judgment, one CST passage (nine or 10 sentences) was presented, and the microphone mode was switched every two or three sentences. The microphone modes were indicated by two lights labeled "#1" and "#2" in front of the listener. Three responses were available: DIR, OMNI, and No Preference. The test was administered in 12 conditions: 2 presentations (AV and auditory only) × 6 SNRs (–10 to +10 dB in 4 dB steps). Each participant expressed four independent preference judgments in each condition. The sentences from two pairs of CST passages were used in one test condition (i.e., one passage in one preference judgment). The orders of passage presentation and AV/auditory-only condition were counterbalanced across the participants. For the same reason mentioned previously, only data obtained in the AV condition and at SNRs of –2, +2, and +6 dB were used in this study.

All tests were administered in a double-walled, sound-treated booth. Speech signals were generated by a computer equipped with a multichannel sound card (LynxTwo), routed via an ART 355 31-band equalizer and a SAMSON Servo 120 amplifier, and then presented from a Tannoy i5 AW loudspeaker located at eye level in one corner of the booth at 0 degrees azimuth. For the HINT, speech signals were routed to a GSI 61 audiometer before being sent to the equalizer. Uncorrelated speech-shaped noise (HINT) and multiple-talker babble (CST) were generated by another computer, routed through equalizers and amplifiers, and presented from six Tannoy i5 AW loudspeakers placed at the top and bottom of the other three corners of the booth. The frequency responses and output of the six corner loudspeakers were adjusted to be equal. Both speech and noise/babble levels were calibrated at the position of the listener's head without the presence of the listener. The distances from the speech loudspeaker and noise loudspeaker to the listener's head were approximately 1.2 and 1.7 m, respectively. The LCD was placed below the speech loudspeaker, which was positioned at 0 degrees horizontal azimuth.

Field-Based Measures

A four-week field trial was carried out to assess the benefit provided by the DMHA in the field using a paired-comparison technique described by Preminger and Cunningham (2003). Specifically, the listener was asked to identify certain environments, listen via the DIR and OMNI modes in those environments, determine his or her preferred microphone mode based on speech intelligibility, and then record the result in a paper-and-pencil journal. To ensure that the participant was in environments optimal for realizing a directional benefit, before each comparison he or she needed to identify a *noisy* environment in which (1) the primary talker was in front of the listener, (2) the talker–listener distance was less than 10 ft, and (3) the noise source(s) was (were) not in front of the listener (Walden et al, 2004).[1] In other words, the participant could compare microphone modes only in environments that acoustically favored directional processing. The participant was asked to do the comparison task three times every day. During the trial of the larger study, the participant was asked to rate hearing aid microphone modes with his or her eyes open for two weeks (AV condition) and with the eyes closed for two weeks. In the AV condition, the participant was instructed to listen in a natural way without emphasizing the role of lip reading in communication. The order in which the participant opened and closed his or her eyes was counterbalanced. For the purpose of this study, data obtained only in the AV condition were used because listening with the eyes open was presumed to be the natural listening mode in the real world.

In order to ensure that the participant collected field data reliably, a training session in the laboratory and a practice field trial were provided. During training, explanations of how to identify environments and make preference judgments were provided. The participant then practiced the comparison task in the sound booth. Specifically, scenarios with different speech/noise locations were created using the AV version of the Speech Perception in Noise test (Kalikow et al, 1977) and presented to the listener. The listener was instructed to identify the locations of speech and noise signals and determine if the listening environment fit the criteria mentioned previously. The listener was then instructed to switch between microphone modes, decide his or her preference, and fill out the journal step by step. Typically, after several practice rounds participants could identify the environment and use the journal effectively. After the training, the subjects were given a test that consisted of 10 scenarios, only half of which favored directional processing. In order to pass the test, the listener had to identify at least nine of 10 environments correctly. Otherwise, the training session was repeated. After the training session and the test, all the participants were considered capable of accurately identifying the environment types and finishing the journal reliably.

The two-week practice field trial was carried out after the participant completed the training and before the real field trial. The participant was given a journal and instructed to fill it out. Two weeks later, the completed journal was reviewed and questions were answered to ensure that the listener could reliably identify the types of environments and complete the comparison task. The data collected in the practice trial were not subjected to analysis.

RESULTS

From laboratory testing, three outcome variables were obtained: HINT-measured directional benefit score, CST-measured directional benefit score, and CST-measured microphone preference score. The HINT-measured directional benefit score was the difference in the threshold between the two microphone modes. Before deriving the CST-measured benefit score, the original CST scores (in percent) were first transformed into rationalized arcsine units to homogenize the variance (Studebaker, 1985). Directional benefit was then derived by subtracting the performance scores of the OMNI mode from the scores of the DIR mode. An averaged directional benefit score across SNRs of –2, +2, and +6 dB was calculated for each participant. To derive the CST-measured preference score, data obtained at those three SNRs were integrated. Specifically, because each participant expressed four independent preference judgments in each of the three SNRs, there were a total of 12 judgments. The CST-measured directional preference score was then defined as the number of comparisons when the listener preferred the DIR mode over the 12 comparisons (in percent). Generalized linear models (GLMs) were used separately in each variable to examine the effect of age (as a continuous variable) on these three scores, controlled for the effect of HFA hearing loss (i.e., the averaged threshold across 1000, 2000, and 4000 Hz).

Prior to other analyses, because it has been shown that reducing low-frequency gain in the DIR mode and a larger vent size could reduce directional benefit (Ricketts, 2000a; Ricketts and Henry, 2002), separate analyses of variance were completed to examine whether these two factors impacted the results. For these analyses the independent variables were gain compensation (equalized and nonequalized), venting (1 mm or smaller, between 1 and 2 mm, and larger than 2 mm), and age group (Old and Young groups). The dependent variables were HINT-measured directional benefit score, CST-measured directional benefit score, and CST-measured directional preference score. The results revealed no significant gain compensation and venting effect and no interaction among the three independent variables, which is in line with the results reported in the literature (Ricketts and Henry, 2002; Freyaldenhoven et al, 2006). Specifically, Ricketts and Henry (2002) found that low-frequency gain compensation reduced directional benefit only for listeners who exhibited hearing thresholds at 500 Hz of 50 dB HL or greater. Further, Freyaldenhoven and colleagues (2006) showed that for low-frequency hearing loss no worse than 55 dB HL, which was the case for the participants of the present study, gain compensation does not have a significant effect on speech understanding in the DIR mode, regardless of vent size. Consequently, all the remaining analyses were completed without consideration of gain compensation and venting as factors.

Figure 3 shows the HINT-measured directional benefit scores as a function of age. Although there is an outlier (i.e., the negative score indicated by the arrow in Figure 3), the benefit scores are similar across listeners of different ages regardless of whether the outlier is considered or not. The analysis using the GLM indicates that age did not have a significant effect on HINT-measured directional benefit score ($F_{1,\ 21} = 0.11$, $p = .74$) when

HFA hearing level was controlled for. As well, neither did HFA hearing loss have a significant effect ($F_{1,\ 21}$ = 0.73, p = .40).

The relationship between CST-measured directional benefit score and age is shown in Figure 4. Note that the benefit scores are small and some of the scores are negative. This is because visual cues (recall that only AV CST data were used in this study) can reduce directional benefit by improving performance in the OMNI mode to ceiling levels (for details, see Wu and Bentler, 2010a). Similar to the HINT score, the CST benefit scores are similar across listeners of different ages. The analysis revealed that age did not have a significant effect on directional benefit score ($F_{1,\ 21}$ = 1.21, p = .29) when HFA hearing level was controlled for, nor did HFA hearing loss have a significant effect on directional benefit ($F_{1,\ 21}$ = 0.19, p = .66). The nonsignificant effect of age on HINT- and CST-measured directional benefit indicates that in the laboratory, listeners of different ages obtained comparable objective benefit from directional processing.

Figure 5 shows CST-measured directional preference scores as a function of age. A higher score indicates that the listener was more likely to perceive directional benefit and prefer the DIR mode in the laboratory comparisons. Since visual cues can reduce directional benefit (Wu and Bentler, 2010a), the DIR mode was not overwhelmingly preferred. The variation in directional preference was large, ranging from 0 to 100% of the time. Figure 5 may initially indicate that older listeners less frequently preferred the DIR mode. However, the analysis revealed that age did not have a significant effect on directional preference ($F_{1,\ 21}$ = 2.94, p = .10) when HFA hearing level was controlled for. HFA hearing loss was found to have a significant effect on directional preference score ($F_{1,\ 21}$ = 4.90, p = .04); a poorer HFA hearing threshold was associated with a higher directional preference score. The nonsignificant effect of age on directional preference indicates that listeners of different ages perceived similar benefit subjectively from directional technology in contrived laboratory environments.

During the field trial, each participant was instructed to identify three listening environments involving the speech-front/noise-not-front configuration and then compare microphone modes. Therefore, the number of evaluations depended on the nature and number of listening environments that the participant encountered in the field trial. A total of 1367 ratings were completed. Among them, 710 ratings were finished with the listeners' eyes open and were used in the study. In the interviews, all the participants reported that when they placed the talkers in front of them, visual cues were almost always available, suggesting that the AV condition in the field trials was the natural listening mode. To perform the analysis, the field directional preference score was defined as the number of comparisons in which the listener preferred the DIR mode over the total comparisons performed by the participant in the field trial (in percent). A higher score indicates that the listener was more likely to perceive the benefit provided by directional processing in the field comparisons. The analysis using the GLM revealed that age had a significant effect on directional preference score ($F_{1,\ 21}$ = 11.78, p = .003): older age was associated with a lower directional preference. In contrast, the HFA hearing threshold itself did not have a significant effect on preference ($F_{1,\ 21}$ = 0.02, p = .90). Figure 6 shows the field directional preference scores as a function of age. Here we see that directional preference score decreases monotonically with increasing age, indicating that older listeners perceived less benefit from DMHAs in their everyday lives than did younger listeners.

Since the laboratory and field data were obtained from the same listeners using the same hearing aids

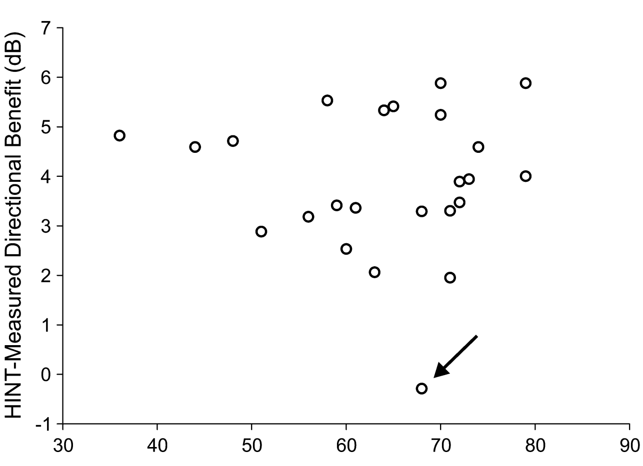

Figure 3. Directional benefit scores measured by the Hearing in Noise Test (HINT) as a function of age. The arrow indicates an outlier.

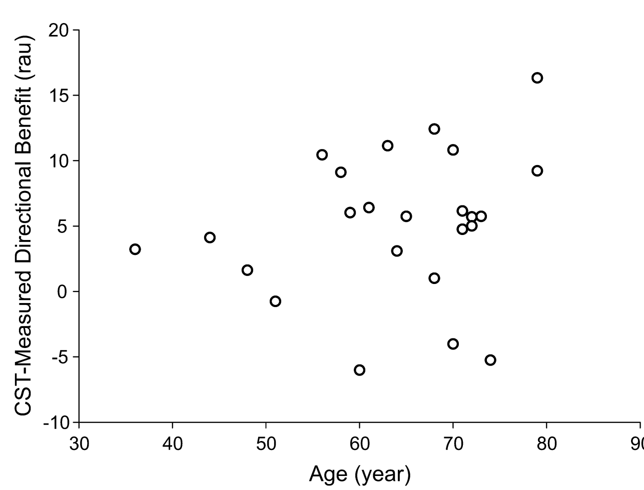

Figure 4. Directional benefit scores measured by the Connected Speech Test (CST) as a function of age.

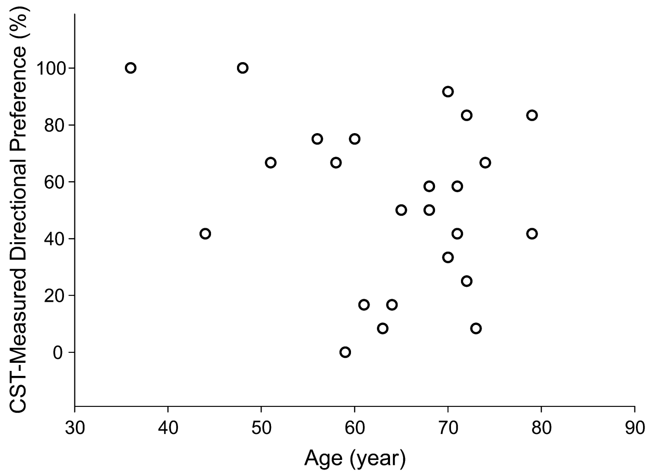

Figure 5. Directional preference scores measured by the Connected Speech Test (CST) as a function of age.

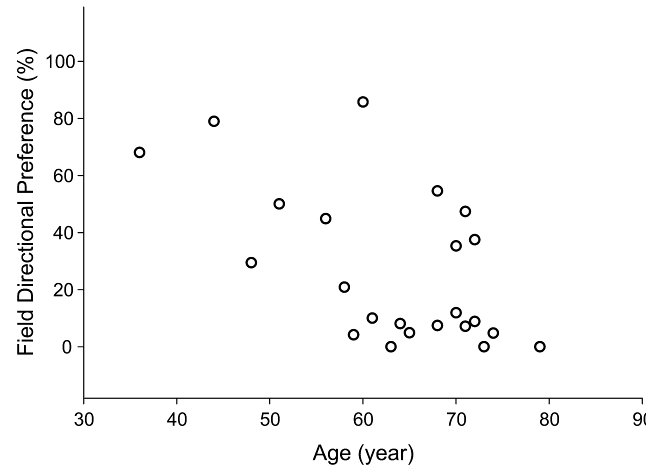

Figure 6. Directional preference scores measured in the field trial as a function of age.

in environments involving similar speech-front/noise-not-front configurations, the two sources of data were compared to determine if field effectiveness data could be predicted by laboratory efficacy data in different age groups. Because it has been shown that the AV CST-measured directional preference score was significantly correlated with the field directional preference score (Wu and Bentler, 2010b), regression analyses between these two variables were performed in the Young and Old groups separately. Figure 7 shows the relationship between the laboratory and field directional preference scores of listeners in the Young and Old groups. The field preference scores increase monotonically with increases in the CST-measured preference score in the Young Group, while field preference is quite similar across different laboratory preferences in the Old Group. Consistent with this observation, regression analyses revealed that, after partialing out the effect of HFA hearing loss, laboratory preference was significantly correlated with field preference in the Young Group ($r = 0.69$, $p = .02$) but not in the Old Group ($r = 0.32$, $p = .34$).

DISCUSSION

The results of this study reveal that hearing aid users of different ages obtain comparable objective directional benefit and perceive similar benefit subjectively from DMHAs in the laboratory, while older users perceive less benefit from the DMHA than do younger users in the real world. In addition, laboratory data can predict real-world outcomes for younger listeners but not for older listeners.

It is encouraging that age does not impact laboratory-measured directional benefit and preference. These results indicate that even though older listeners have more difficulty understanding speech in noise, these listeners still can take the same advantage of the improved SNR provided by directional processing as can younger listeners. The laboratory results might provide the rationale for fitting older hearing-impaired adults across different ages with DMHAs.

However, although younger and older listeners benefited equally from directional processing in the laboratory, the DMHA did not work very well for older listeners in their own environments. Although old age is commonly assumed to be associated with a decline in ability to learn new skills (Kausler, 1991), considering that the participants in this study were effectively trained to identify listening environments and that they underwent a two-week practice field trial before the data were collected, it is unlikely that the older listeners did not understand how to select the correct environments for comparing microphone modes in the field trial. It could be possible that other age-related factors were responsible for the smaller perceived benefit of the DMHA by older listeners in the real world. Further, because laboratory efficacy data were shown not to predict field effectiveness for older listeners, it is likely that these factors are not incorporated into current laboratory testing environments and protocols. The factors may include age-related social changes and age-related cognitive changes.

Age-Related Social Changes May Affect DMHA Benefit in the Real World

Generally, older people interact less socially, pursue fewer social activities, and have smaller social networks (e.g., Palmore, 1981; Lang and Carstensen, 1994).[2] This reduced social contact may be due, in part, to health restrictions (Bukov et al, 2002), but other explanations have been suggested. One of the theories seeking to explain older adults' social behaviors is the *socioemotional selectivity theory* (Carstensen, 1992; Carstensen et al, 2006). According to this theory, people's needs for

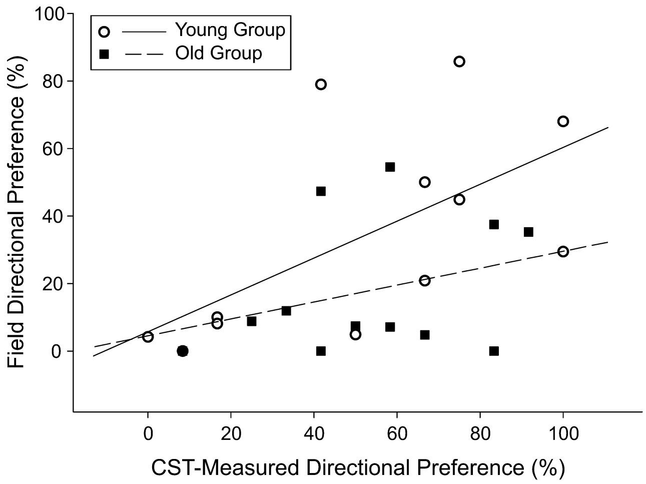

Figure 7. Field directional preference scores as a function of Connected Speech Test (CST)–measured directional preference score for younger and older participants. The regression lines between the two sources of directional preference illustrate a general relationship between these two variables.

social contact change as they grow older. For younger people, when time is perceived as open ended, they desire and seek social contact to meet information-seeking goals. To this end, broad and diverse social interaction provides the opportunity to access information. For older people, when time is perceived as limited, they become less interested in seeking novel experiences, preferring to invest in sure things, deepen existing relationships, and savor life. Therefore, older people tend to maintain a smaller circle of closer friends.

According to the socioemotional selectivity theory, elderly listeners may obtain only limited DMHA benefit in their everyday lives. Specifically, if older listeners tend to experience less social interaction and are not eager to seek new information, they may not encounter many demanding (e.g., noisy) listening environments. For example, an older listener may choose not to attend a party because he or she is not interested in making new friends. In contrast, a younger listener may attend the party because he or she is eager to (or is forced to) seek new friends or information. In fact, because elderly listeners have more difficulty with speech in noisy contexts, they may try to avoid noisy environments intentionally. As a result, if most of their listening environments are not very noisy, elderly listeners may not obtain much benefit from the DMHA because the directional microphone does not improve speech intelligibility to a significant degree if the noise level is not sufficiently high (Walden et al, 2005; Wu and Bentler, 2010a). Additionally, if older listeners encounter fewer noisy environments, they might regard as noisy one that others may find relatively quiet. As a result, older listeners may obtain limited benefit from the DMHA in their “noisy” environments.

The benefit of the DMHA may also be reduced by the fact that older adults spend most of their time with closer friends, as suggested by the socioemotional selectivity theory. Specifically, because communication with familiar talkers can improve speech perception (Yonan and Sommers, 2000), the improved level of perception may have already approached the inherent limit of the listener’s speech-recognition ability (i.e., ceiling), even with the hearing aid in the OMNI mode. If so, a hearing aid user will only obtain a small benefit when she or he switches the OMNI mode to the DIR mode (Walden et al, 2005; Wu and Bentler, 2010a).

Several studies have suggested that elderly listeners have more difficulty understanding speech in noise, compared to younger listeners with similar degrees of hearing loss, and still report that hearing impairment causes *less* social and emotional impact on their daily lives (Gordon-Salant et al, 1994), *fewer* communication problems (Garstecki and Erler, 1996), and *less* hearing disability (Uchida et al, 2003). One of the possible explanations for these paradoxical results is the fact that elderly people in retirement have fewer communication demands placed on them (Uchida et al, 2003; Gordon-Salant, 2005).

If older hearing aid users’ listening environments are less noisy than those of younger users, current laboratory or clinical testing of the DMHA may not be appropriate for elderly listeners. Specifically, according to Pearsons and colleagues (1976), the real-world SNR of relatively noisy environments (e.g., department stores, hospitals, trains, and aircraft) is usually defined as between –1 to +4 dB. This range of SNR has been used in a number of DMHA and hearing aid studies (e.g., Ricketts, 2000b; Surr et al, 2002; Bentler, Egge, et al, 2004). It is likely that because these poor SNRs as used in the laboratory are rarely encountered by elderly hearing aid users, the laboratory data obtained from these listeners cannot predict their real-world outcomes.

Age-Related Cognitive Changes May Affect DMHA Benefit in the Real World

Many cognitive abilities decline with increasing age, including information processing speed, attention skill, and working memory (Craik and Salthouse, 2008). Some cognitive functions have been shown to be related to an individual’s ability to report the effect of hearing aid signal processing. For example, Lunner (2003) found that hearing aid users with poorer working memories were less capable of using a questionnaire to accurately identify and report the difference between a hearing aid’s two noise-reduction algorithms. That is, because working memory is presumed to be related to the task of reasoning, listeners with poorer working memories could not correctly remember and integrate their perception when answering the questionnaire after a 1 mo field trial (Lunner, 2003). Yet working memory is not the only cognitive ability related to the limited benefit of the DMHA found in this study, as listeners could and did record what they perceived in the field immediately after the microphone comparison, rather than at some later time.

Attention is another cognitive ability that might be responsible for the limited benefit of the DMHA and for the laboratory–field discrepancy in older listeners. Specifically, when a hearing aid user tries to determine which microphone mode is better in a given environment, he or she usually switches between the DIR and OMNI modes, listens, and then makes a judgment. This scenario is very similar to the paired-comparison technique used in many studies (Walden et al, 2005; Amlani et al, 2006; Wu and Bentler, 2010a). In typical laboratory paired-comparison procedures, the listener is asked only to *passively listen* to speech and then express his or her preference. Because the listener is not asked to *comprehend* speech and because there is no distracter to interfere with the comparison task in the simplified laboratory setting, the listener can usually concentrate on the comparison task. In contrast, when trying to compare microphone modes during a conversation in the real world, the listener, in addition to the comparison task, often needs to perform several other tasks simultaneously, such as comprehending the speech, responding to the speech (i.e., engaging in conversation), and locating/pressing the tiny buttons on the hearing aids to change microphone modes from time to time. In addition, the listener may, for example, need to walk or watch for traffic. As a result, the listener may not be able to concentrate on the comparison task. In other words, diversion of attention from the comparison task to other tasks may lead to the difficulty of older listeners in perceiving the benefit of the DMHA in the real world, even if DMHAs do provide benefit in certain real-world situations.

Among various attention skills, *divided attention* is the one that seems to relate most closely to perceiving DMHA benefit. Divided attention is the ability to concurrently attend to and process information from different sources or concurrently perform and switch among different tasks (Kramer and Madden, 2008). Previous studies have found that older adults frequently experience greater interference under dual-task conditions than do younger adults (Allen et al, 1998; Hartley, 2001; Kramer and Madden, 2008). One example of a dual-task deficit in the real world is cell phone use while driving. It has been shown that cell phone conversations during driving result in substantially longer reaction times in the user's braking response, or more misses in fast reaction response, relative to the control condition (i.e., driving only [Strayer and Johnston, 2001; Consiglio et al, 2003; McCarley et al, 2004; Morel et al, 2005]). The cell phone dual-task deficit is substantially larger for older adults (McCarley et al, 2004). More important, the additional task of listening to radio music or to a book on tape does not have this effect (Consiglio et al, 2003; Morel et al, 2005), indicating that speech comprehension and conversation draw more cognitive resources and generate larger interference than does passive listening. Therefore, it is likely that older listeners with poorer divided attention skills cannot perceive DMHA benefit in the real world because the comparison task requires more attention in the real world than it does in the laboratory.

CONCLUSION

In summary, it is likely that due to their unique social lifestyles (i.e., inhabiting fewer noisy listening environments and/or communicating with more familiar talkers), older listeners cannot obtain a significant benefit from the use of the DMHA in their daily lives. Even if elderly listeners can benefit from the DMHA in certain real-world environments, they may not notice this benefit because of the diminishment of their attention abilities. More research is needed to clarify these issues. If the former is true, audiologists should pay more attention to clients' social lifestyles before fitting DMHAs. For those who do not encounter many demanding listening environments, providing the directional microphone may not be too helpful. For hearing aid manufacturers, listeners' lifestyle information may be used as an input to tailor the decision rules of automatic directional systems. If the latter is true, DMHAs may still be recommended for older hearing-impaired people. However, consultations should be provided to help them adjust their expectations regarding the small perceivable benefit provided by DMHAs. Furthermore, it seems that because current laboratory testing environments and protocols are not valid for older listeners (e.g., laboratory SNRs are much poorer than those encountered in older listeners' lives or laboratory testing is not cognitively demanding), laboratory data cannot predict older listeners' field outcomes. More research is needed to determine if laboratory data would be more predictive after considering the effects of age-related social and cognitive changes in testing environments and protocols.

NOTES

1. Because the larger study was designed to examine the effect of visual cues on DMHA benefit, there was one more criterion: The participant could see the talker's face at least sometimes in that environment.
2. There is little consistency in the usage and precise meaning of the concepts of social engagement, social network, social support, social activity, social integration, and social participation (Mendes de Leon, 2005). In this article these terms are used interchangeably.

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