Comparison of Benefits Provided by Various Hearing Aid Technologies in Older Adults

Larry E. Humes, Dana Kinney, Elizabeth Thompson

Abstract

This article presents two different sets of data comparing the outcomes measured with different hearing aid technologies. In the first data set, performance on a fairly comprehensive core battery of hearing-aid outcome measures was obtained for five different technologies, ranging from analog single-channel linear in-the-ear devices with output-limiting compression and omnidirectional microphones to digital six-channel digital wide-dynamic-range-compression "open-fit" behind-the-ear devices having directional microphones. Despite the wide range in technologies and a fairly broad set of outcome measures, few significant differences in outcome were observed across technologies. In the second data set, an expanded battery of outcome measures was employed and the technology comparison was restricted to a comparison of omnidirectional versus directional microphones on digital four-channel devices. Here, again, few differences in outcome were observed. Thus, when hearing aids are fit within a comprehensive assessment and treatment protocol and close matches to prescriptive targets for gain and maximum output are obtained, as was the case for all the technologies compared here, the particulars of the technology do not appear to have an appreciable impact on measured hearing-aid outcome.

Introduction

Over the past dozen years or so, a series of studies on hearing-aid outcome measures has been conducted at Indiana University under the direction of the first author. The primary purpose of these studies was to determine both what should be measured and when it should be measured, when it comes to hearing aid outcome measures, and to study what factors contributed to individual differences in outcome among wearers. The target population in all studies was older adults, 60–89 years of age, with bilateral high-frequency sensorineural hearing loss typical for their age. This group purchases roughly two thirds of the hearing aids sold in the U.S. (e.g., Skafte, 2000; Strom, 2006). These studies of hearing-aid outcome have been summarized in a series of publications from our laboratory (Humes et al., 2000, 2001, 2002a, 2002b, 2004; Humes, 2001, 2002, 2003, 2007; Humes & Wilson, 2003).

Within each study, a detailed comprehensive fitting and evaluation protocol was followed and the technology was held constant. The latter constraint was imposed because of the focus on individual differences in outcome. That is, we were most interested in what it was about the individual wearer that determined successful outcomes, rather than what it was about various technologies that impacted outcome. Of course, as soon as one protocol was completed, often over a period of from 1–3 years, contemporary hearing aid technology had changed. This led to questions about whether results obtained with earlier technologies could be generalized to now new contemporary technologies. This, in turn, led to the conduct of new studies of hearing aid outcome, each ultimately making use of different technologies. (Again, within a study, the technology was held constant.)

Now, many years later and after the completion of several such studies of hearing-aid outcome, an opportunity was presented to us to retrospectively compare group data across studies or technologies. This was possible due, in part, to the use of a common core battery of

Address correspondence to: Indiana University, Department of Speech & Hearing Sciences, Bloomington, IN 47405-7002, Larry E. Humes, humes@indiana.edu, (812) 855-3507 (ph), (812) 855-5531 (fax)

hearing aid outcome measures included in each study and the use of reasonably large samples in many of the studies. Humes et al. (2009) published a comparison of outcome measures for several of these technologies, ranging from analog single-channel linear Class-D devices with output-limiting compression, a technology "dinosaur" by today's standards, to digital four-channel wide-dynamic-range-compression (WDRC) devices with directional or omnidirectional microphones. The groups fitted with each of the four technologies evaluated in the study by Humes et al. (2009) were each comprised of about 50 individuals with similar audiometric configurations, ages, gender composition, and proportions of new hearing aid wearers. Somewhat surprisingly, very few group differences in hearing-aid outcome were observed. The primary exception was aided sound-field speech-recognition performance in noise for which the hearing aids with directional microphones yielded significantly superior performance. This was expected, however, given the location of the speech signal source at 0-degree azimuth and the noise source at 180-degrees azimuth, which were in close proximity to the null in the directional microphone's polar plot. Again, this was the lone difference in outcome across technologies. No differences were observed on multiple self-report measures of outcome, including measures of hearing-aid benefit, satisfaction and usage (Humes et al., 2009).

An Updated Comparison of Technologies for a Core Battery of Outcome Measures

Since the publication of these outcome comparisons for various technologies by Humes et al. (2009), another assessment of hearing aid outcomes has been completed by our laboratory, this time for contemporary "open-fit" behind-the-ear devices. The devices evaluated by our laboratory were digital six-channel WDRC devices with directional microphones. Once again, a detailed and comprehensive evaluation and fitting protocol was followed and the core battery of hearing-aid outcome measures was again employed (as well as some additional outcome measures not described here). In addition, as in the earlier studies, real-ear measurements were used for verification of prescribed gain and maximum output targets. In this case, NAL-NL1 (Dillon et al., 1998; Dillon, 1999) was used to generate targets for gain and individually measured loudness discomfort levels at 500, 1000, 2000 and 4000 Hz were used for adjustments of maximum output. A total of 35 older adults were fitted with these open-fit devices and completed the battery of outcome measures at about six weeks post-fit. The primary difference between this group of 35 participants and the groups of about 50 participants fitted with other technologies and described in Humes et al. (2009) was that the open-fit group had about 4–10 dB better hearing thresholds in the higher frequencies (2000–8000 Hz) than the other groups (consistent with fitting guidelines for these devices).

The core battery of outcome measures, common to all studies, consisted of the following measures. The Connected Speech Test (CST; Cox, Alexander & Gilmore, 1988) was presented at a conversational level of 65 dB SPL and a typical signal-to-noise ratio of +8 dB. The speech was presented from a loudspeaker one meter in front of the listener at 0-degree azimuth and the noise, a multi-talker babble from the CST, was presented from an identical loudspeaker located at 180-degree azimuth. The CST was completed both aided and unaided and on two separate occasions (4-6 weeks apart), with the two unaided and two aided measurements averaged. In addition to the CST, several self-report measures of outcome were completed at six weeks post-fit. These included: (1) the Hearing Aid Performance Inventory (HAPI; Walden et al., 1984), a measure of self-reported benefit or "helpfulness" of hearing aids; (2) the Glasgow Hearing Aid Benefit Profile (GHABP; Gatehouse, 1999), which was reduced here to three subscales of benefit, satisfaction, and usage; (3) a slightly modified Marke-Trak-V (Kochkin, 2000) satisfaction survey, referred to as the Hearing Aid Satisfaction Survey (HASS) in other publications from our laboratory, with a focus on the two of the three available scales – those evaluating satisfaction with hearing aid features (size, batteries, volume control, etc.) and listening situations (quiet, noise, group conversation, etc.); and (4) a daily hearing aid usage diary in which the wearer logged the hours the hearing aids were used each day, as well as any problems that arose, then turned in these diaries at study completion (six-weeks post-fit).

Figure 1 compares the group means and standard deviations for the open-fit devices (black vertical bars) to those evaluated with other technologies by Humes et al. (2009). CST scores are shown for unaided (left) and aided (middle) listening conditions, as well as the difference between these two scores, or the relative "benefit" measured (right). Note that the group with open-fit devices has higher CST scores for both aided and unaided listening conditions, compared to the four groups fitted with other hearing-aid technologies, but that the relative

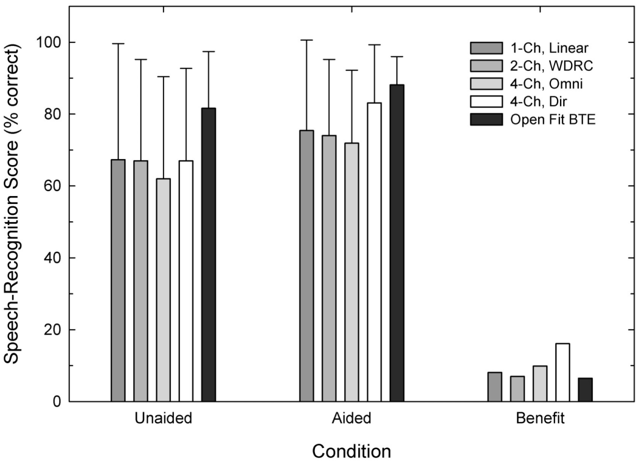

Figure 1: Means and standard deviations (error bars = 1 SD) for the percent-correct scores from the CST for each of the five participant groups. Speech was presented at 65 dB SPL and multi-talker babble at 57 dB SPL (+8 dB signal-to-babble ratio) with unaided scores on the left, aided scores in the middle, and differences between aided and unaided (benefit) on the right. Aided and unaided scores had been provided previously by Humes et al. (2009), except for the open-fit BTE group. Relative benefit values are new to this figure.

benefit for the open-fit devices does not differ much from that measured in at least three of the other four technologies. Recall that the primary difference between the group fit with open-fit devices and the groups fit with other technologies was that the former had appreciably better (4–10 dB) high-frequency hearing thresholds than the other groups. This better high-frequency hearing sensitivity is most likely the reason for the higher unaided CST scores observed for the open-fit group. It also most likely impacts the aided scores as well. Consistent with this supposition, the correlation between aided and unaided CST scores for the group fit with open-fit devices was $r = 0.68$ ($p < .01$).

To examine these group differences in CST performance in greater detail, the percent-correct scores were transformed to rationalized arcsine units (Studebaker, 1985) to stabilize the error variance and two univariate General Linear Model (GLM) analyses of group differences were performed, one for the unaided scores and one for the aided scores. Importantly, given the slightly milder high-frequency hearing loss for the open-fit group, the bilateral high-frequency pure-tone average (mean of thresholds at 1000, 2000 and 4000 Hz) was introduced as a covariate. The GLM analyses were followed up by Bonferroni-adjusted multiple t-tests. For the unaided CST, no significant differences were observed among the groups ($p > .10$), following adjustment for differences in hearing loss. For the aided CST scores, however, a significant effect ($p < .001$) of hearing-aid technology group was observed. Follow-up t-tests revealed that the aided CST scores for the group fit with 4-channel directional hearing aids were significantly ($p < .05$) better than those from all other groups except for the open-fit group. Similarly, the scores from the open-fit group were not significantly different from the group fit with the 4-channel directional hearing aids, but were significantly ($p < .05$) better than those from two of the three remaining groups and approached significance ($p = 0.056$) for the other group. For all technologies, the relative benefit observed was significantly greater than zero.

Recall that the open-fit devices evaluated here also had directional microphones. Thus, the group data for the aided CST scores indicates that the two groups fit with directional devices yielded superior aided speech-recognition performance in background noise compared to the three groups with technologies employing omnidirectional microphones. This was true even for the open-fit devices. Ricketts (2000) argued, based on acoustical directivity-index measurements, that there would be minimal directional benefits from open-fit devices because the noise in the low and mid frequencies could pass directly through the open fitting or vent. Valente and Mispagel (2008), however, measured speech-recognition performance directly in an open-fit device with a directional microphone and observed a mean directional benefit of 1.9 dB, somewhat smaller than the 2–5 dB typically measured under the same conditions for occluding fits. Unfortunately, for the open-fit group included here, a comparison to omnidirectional open-fit devices for the same wearers was not obtained. Nonetheless, the aided speech-recognition performance in noise for both directional devices examined by our laboratory, including the open-fit device, was superior to that observed for omnidirecitonal devices, even after controlling for the better hearing sensitivity of the group fit with open-fit devices.

Figure 2 depicts the means and standard deviations from the HAPI for the group with open-fit devices (black vertical bars) and the groups fit with other technologies evaluated by Humes et al. (2009). Although the trend is for the mean HAPI scores for the open-fit technology (black bars) to be somewhat higher (worse) than those for several other technologies, there were no significant differences in performance observed on the HAPI.

Figure 3 provides the means and standard deviations for the five groups fitted with different technolo-

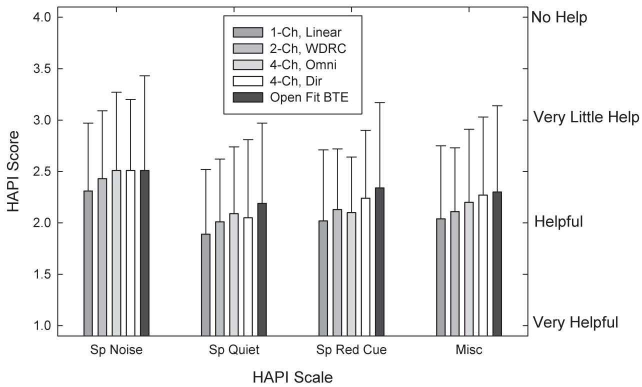

Figure 2: Means and standard deviations (error bars = 1 SD) for the four HAPI subscales and each of the five groups of hearing aid wearers. Note that lower scores are better on the HAPI.

gies on several self-report outcome measures. These include the average hours of usage, as calculated from the wearer's daily diaries, three measures from the GHABP (usage, helpfulness, satisfaction), and the HASS (a minor variation of the MarkeTrak satisfaction survey). The group wearing open-fit devices (black vertical bars) again does not differ significantly in average performance from any of the other groups fitted with different technologies.

In summary, analysis of the outcome measures from 35 older adults fit with digital, six-channel WDRC open-fit behind-the-ear devices with directional microphones revealed that the outcomes did not differ appreciably from those outcome measures obtained from other "earlier" technologies. This was true, moreover, across a relatively wide array of outcome dimensions, including aided and unaided speech-recognition performance, usage, satisfaction, and benefit. Thus, when a comprehensive and detailed fitting protocol is used, including real-ear verification of gain and output targets, the technology used to accomplish those targets appears to be relatively unimportant. It should also be noted that not only were the outcomes roughly "equal", but they were "equally good". That is, it was not the case that all technologies yielded poor performance when carefully fitted. Rather, in general, significant benefit of about 8–12% was measured in speech recognition from unaided to aided listening, wearers reported that their devices were "helpful" and that they were "satisfied" with them, and they wore the hearing aids typically for 8 hours per day. In each case, these would generally be considered to be quite positive outcomes.

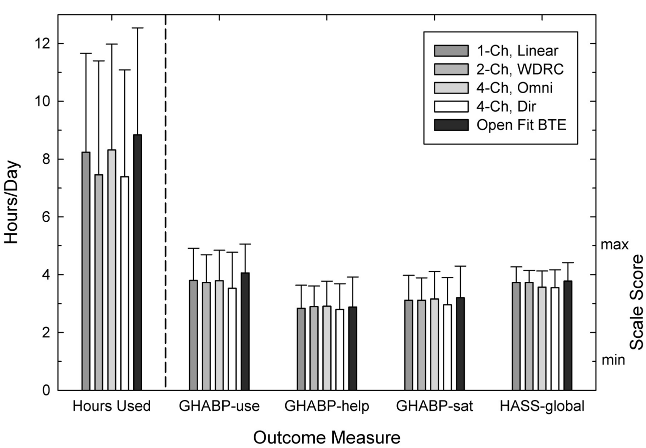

Figure 3: Means and standard deviations (error bars = 1 SD) for the three GHABP scales (middle), daily use diaries (far left), and the HASS (far right) for each of the five groups in this report. Daily usage logs at the far left make use of the left ordinate ("Hours/Day") whereas the other four self-report measures make use of the right ordinate ("Scale Score"). For all measures, higher values indicated better outcomes.

An Expanded Battery of Outcome Measures for One Technology Comparison

Even though the core battery of outcome measures tapped several key dimensions of hearing aid outcome (Humes, 2003), it is always possible that we were not looking at dimensions that might reveal differences in technologies. To address this possibility, an expanded set of outcome measures were included in a comparison of directional microphone technologies. In addition to the core battery measures noted previously (CST, HAPI, GHABP, HASS, and usage diaries), the following additional outcome measures were obtained: (1) an additional measure of satisfaction, the Satisfaction with Amplification in Daily Life (SADL) scale (Cox & Alexander, 1999); (2) a modified version of the Acceptable Noise Level (ANL; Nabelek et al., 2006), which made use of similar, but not identical, speech and competing stimuli; (3) a measure of loudness and loudness satisfaction, the Profile of Aided Loudness (PAL; Mueller & Palmer, 1998); (4) an abbreviated version of a Judgments of Sound Quality (JSQ) test (Narendran & Humes, 2003) for both speech and music stimuli; and (5) a version of the Functional Assessment of Non-Life Threatening Conditions (FANTLC, Cella et al., 1993), adapted for hearing loss as the non-life threatening condition.

There were a total of 109 older adults who participated with 53 arbitrarily assigned to the group receiving omnidirectional technology and 56 assigned to the group receiving directional technology. Eligible and confirmed participants were assigned to each group in alternating fashion at the time of enrollment. Participants were blinded as to which group they were in. The two groups did not differ significantly ($p < .05$) in age (mean ages of 75.4 and 74.5 years), bilateral average high-frequency (1000, 2000, and 4000 Hz) hearing loss (50.3 and 50.9 dB HL), percentage of males (60% and 71%) or the percentage of new hearing-aid wearers (67% and 71%). The hearing aids, fit bilaterally, were digital four-channel, WDRC devices programmed for gain and output in accordance with NAL-NL1 prescriptive targets. Individually measured loudness discomfort levels for pure tones at 500, 1000, 2000 and 4000 Hz were used or the setting of maximum output. The devices and programming of these devices was identical in all respects, except for the software setting of the microphones. NAL-NL1 targets were generated using software supplied by NAL rather than the manufacturer. As in other studies of hearing aid outcome in our laboratory, good matches to targets were verified using real-ear measurements. On average, however, there was 2–5 dB lower real-ear gain in the mid frequencies for the group fit with directional microphones compared to those fit with omnidirectional microphones, despite having equivalent mean audiograms in this same frequency region. In addition, in a subgroup of 38 of the 56 participants in the group with directional microphones or 68% of this group, electroacoustic measurements performed with Audioscan's Verifit system confirmed the function of the directional systems. (This system was not available for use for the initial 18 participants assigned to this group and, as a result, these measures were not completed on their devices.)

The mean results (and standard deviations) for the measures from the core battery of hearing-aid outcome were presented previously as the light grey (omnidirectional) and white (directional) vertical bars in Figures 1 through 3. Among these measures, the only significant difference observed was for the aided CST score (Figure 1), with the group using directional microphones scoring significantly higher in these test conditions than the group wearing devices with omnidirectional microphones. No other group differences for the comparisons of omnidirectional and directional microphones were significant among this core battery of outcome measures.

Among the additional outcome measures comprising the expanded battery, the measure most like the CST is the ANL. For this measure, the most comfortable presentation level is established for the speech signal in quiet. Then, a background noise is introduced and the level corresponding to that which the listener chooses not "to put up with" for any length of time is established. The relative difference in the speech and noise levels is the "acceptable noise level", or ANL, in dB. In this study, the speech originated from 0-degrees azimuth and the noise from 180-degrees azimuth, just as in the measurement of CST scores. (The null in the hearing aid's polar plot is described as being very close to 180-degrees azimuth by the manufacturer.) The listener's tasks in the ANL and CST measurements are considerably different, but the stimuli are quite similar. Does the ANL also show a directional benefit as did the CST? Figure 4 reveals that this was, in fact, the case. When a mixed-model 2 x 2 factorial GLM analysis was performed, the main effects of listening condition (aided vs. unaided) and microphone (directional vs. omnidirectional) were not significant ($p > .05$), but the interaction between these two factors was significant ($p < .01$). From Figure 4, there are no differences in ANL between unaided and aided listening conditions for the omnidirectional group, but the aided ANL is significantly lower (better) than the unaided ANL for the directional group. Thus, on average, when the directional microphone was used, about 2–2.5 dB of additional noise could be tolerated in the

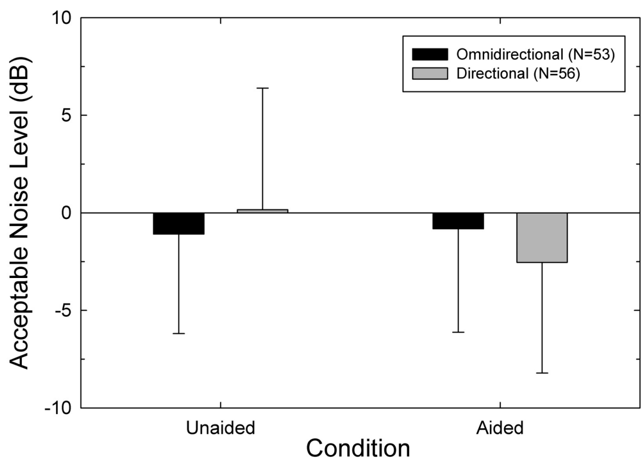

Figure 4: Means and standard deviations (error bars = 1 SD) for unaided (left) and aided (right) acceptable noise levels (ANLs). Black bars represent the data from the 53 older adults fit with omnidirectional microphones whereas grey bars represent the group data for the 56 older adults fit with directional microphones.

aided condition by the listeners in this group than in the unaided condition whereas no such benefit was observed in the group wearing devices with omnidirectional microphones.

Thus, the two acoustically based outcome measures completed in the sound booth, the CST and the ANL, both revealed significant benefits of directional microphone technology. In both cases, moreover, the sizes of the directional benefits were relatively small, amounting to about a 10% higher CST score or a 2-dB improvement in ANL. On an individual basis, however, there was not a significant correlation between performance on the ANL and the relative benefit measured on the CST for either the entire data set ($r = 0.07$, $p > .10$) or for just those fit with directional microphones ($r = 0.15$, $p > .10$).

The other components of the expanded hearing-aid outcome battery failed to reveal any significant differences in outcome between the two groups of hearing aid wearers. This is illustrated in Figure 5 for two of the additional measures, the JSQ and the PAL. For the JSQ, three subscales were established based on factor analysis of the eight scales of sound quality and the three vertical bars in the left portion of Figure 5 represent the mean scores on each of the resulting JSQ subscales. JSQ ratings assigned by the participants during testing can range from 0 to 10. For the PAL, both loudness ratings and satisfaction-with-loudness ratings were obtained for sounds of soft, average, or loud level. The loudness ratings range from values of 0 to 7 whereas the loudness-satisfaction ratings can range from 1 to 5. Thus, there are six possible subscale scores for the PAL (3 loudness levels and 2 types of ratings for each) and the mean results for each of these six subscales are shown in the right-hand portion of Figure 5. For the JSQ and the PAL, as was the case for all other measures in the expanded set of outcome measures except the ANL, there were no significant differences in outcome between the groups with directional (grey vertical bars) and omnidirectional (black vertical bars) microphones. Also consistent with the findings from the core battery and a wider range of technologies, the average outcomes, while not different across technologies, are generally "good" or "positive" regarding hearing aid outcome in general. For example, the mean loudness-satisfaction ratings from the PAL for soft, average, and loud sounds for both directional and omnidirectional technologies correspond to ratings between "OK" and "pretty good". Likewise, the "normal hearing ideals" for the JSQ ratings are generally between ratings of 6 and 8 across the eight scales (Gabrielsson, Schenkman & Hagerman, 1988), with the data in Figure 5 indicating that the hearing aid wearers are at or approaching normal-hearing ideals for sound quality while listening with their hearing aids.

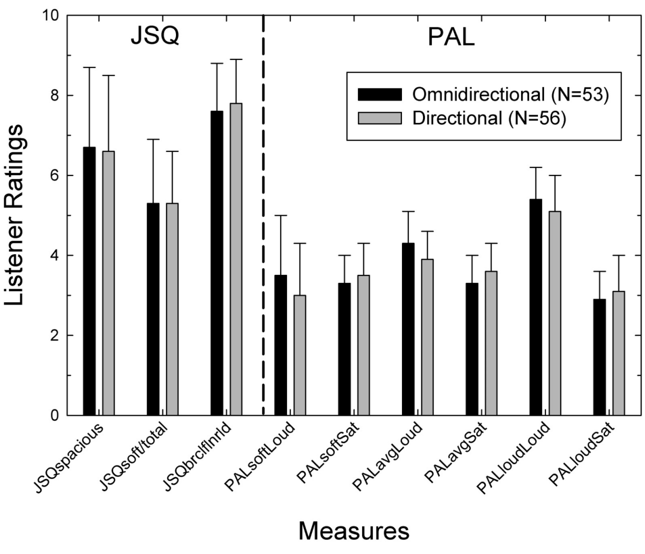

Figure 5: Average listener ratings for the omnidirectional (black bars) and directional (grey bars) groups on the Judgments of Sound Quality (JSQ) and Profile of Aided Listening (PAL) tests.

In summary, adding a wider array of outcome measures did not result in greater evidence regarding the differential benefits afforded by hearing aid technologies; in this case, directional microphones. Once again, however, when the devices were fit with a detailed and comprehensive protocol and good matches to targets were obtained, the general outcomes were quite positive for *both* omnidirectional and directional microphones. At the time the protocol for the study of directional technologies was being developed, there were few, if any, outcome measures specifically targeting directional hearing. Since then, however, the Speech, Spatial and Qualities of Hearing Scale (SSQ) has been developed (Gatehouse & Noble, 2004) and evaluated in relatively large groups of hearing aid wearers (Noble & Gatehouse, 2006). For the specific issue of evaluating directional versus omnidirectional technologies, the SSQ may prove to be a particularly useful tool to supplement the core battery of outcome measures.

Acknowledgements

This work was supported, in part, by NIA R01 AG008293. Thanks to Nathan Amos, Nancy Barlow, Gretchen Burk, Carolyn Garner, and Lisa Goerner for their assistance with data collection, and to many Au.D. and graduate students for their assistance with data entry.

References

Cella, D.F., Tulsky, D.S., Gray, G., Sarafian, B., Lloyd, S., Linn, E., Bonomi, A., Silberman, M., Yellen, S.B., Winicour, P., Brannon, J., Eckberg, K., Purl, S., Blendowski, C., Goodman, M., Barnicle, M., Stewart, I., McHale, M., Bonomi, P., Kaplan, E., Taylor, S., Thomas, C., & Harris, J. (1993). The Functional Assessment of Cancer Therapy (FACT) scale: Development and validation of the general measure. *Journal of Clinical Oncology,* 11, 570–579.

Cox, R.M. and Alexander, G.C. 1999. Measuring Satisfaction with Amplification in Daily Life: The SADL scale. *Ear and Hearing,* 20, 306–320.

Cox, R. M., Alexander, G. C., & Gilmore, C. (1987). Development of the Connected Speech Test (CST). *Ear and Hearing,* 8(5 Suppl), 119S-126S.

Dillon, H. 1999. NAL-NL1: A new prescriptive fitting procedure for non-linear hearing aids. *The Hearing Journal,* 52(4), 10–16.

Dillon H, Byrne D, Brewer S, Katsch R, Ching T, & Keidser G. (1998). NAL NonlinearVersion 1.01 *User Manual*. Chatswood, Australia: National Acoustics Laboratories.

Gabrielsson, A., Schenkman, B.N., and Hagerman, B. 1988. The effects of different frequency responses on sound quality judgments and speech intelligibility. *Journal of Speech and Hearing Research,* 31, 166–177.

Gatehouse, S. (1999). Glasgow Hearing Aid Benefit Profile: Derivation and validation of a client-centered outcome measure for hearing aid services. *Journal of the American Academy of Audiology,* 10, 80–103.

Gatehouse, S. and Noble, W. 2004. The speech, spatial, and qualities of hearing scale (SSQ). *International Journal of Audiology,* 43, 85-99.

Humes, L. E. (2001). Issues in evaluating the effectiveness of hearing aids in the elderly: What to measure and when. *Seminars in Hearing* 22(3), 303–314.

Humes, L. E. (2002). Factors underlying the speech-recognition performance of elderly hearing-aid wearers. *Journal of the Acoustical Society of America,* 112, 1112–1132.

Humes, L. E. (2003). Modeling and predicting hearing-aid outcome. Trends in Amplification, 7, 41–75.

Humes, L.E. (2007) Hearing-aid outcome measures in older adults. In Palmer, C.A. and Seewald, R.C. (Editors), *Hearing Care for Adults 2006*, Phonak AG: Stäfa, Switzerland, pp. 265–276.

Humes, L. E. & Wilson, D. L. (2003). An examination of the changes in hearing-aid performance and benefit in the elderly over a 3-year period of hearing-aid use. *Journal of Speech, Language, and Hearing Research,* 46, 137–145.

Humes, L. E., Humes, L. E., Wilson, D. L. (2004). A comparison of single-channel linear amplification and two-channel wide-dynamic-range-compression amplification by means of an independent-group design. *American Journal of Audiology,* 13, 39–53.

Humes, L.E., Ahlstrom, J.B., Bratt, G.W., & Peek, B.F. (2009). Studies of hearing aid outcome measures in older adults: A comparison of technologies and an examination of individual differences. *Seminars in Hearing,* 30, 112–128.

Humes, L. E., Barlow, N. N., Garner, C. B., & Wilson, D. L. (2000). Prescribed clinician-fit versus as-worn coupler gain in a group of elderly hearing-aid wearers. *Journal of Speech, Language, and Hearing Research,* 43, 879–892.

Humes, L. E., Garner, C. B., Wilson, D. L., Barlow, N. N. (2001). Hearing-aid outcome measures following one month of hearing aid use by the elderly. *Journal of Speech, Language, and Hearing Research,* 44, 469–486.

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B. (2002a). Measures of hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Journal of Speech, Language, and Hearing Research,* 45, 772–782.

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B., & Amos, N. E. (2002b). Longitudinal changes in hearing-aid satisfaction and usage in the elderly over a period of one or two years after hearing-aid delivery. *Ear and Hearing,* 23, 428–437.

Kochkin, S. (2000). MarkeTrak V: Consumer satisfaction revisited. *The Hearing Journal,* 53(1), 38–55.

Mueller, H.G. and Palmer, C.V. 1998. The profile of aided loudness: a new "PAL" for '98. *Hearing Journal* 51(1), 10–17.

Nabelek, A.K., Freyaldenhoven, M.C., Tampas, J.W., Burchfield, S.B. and Muenchen, R.A. 2006. Acceptable noise level as a predictor of hearing aid use. *Journal of the American Academy of Audiology* 17, 626–639.

Narendran, M.M. and Humes, L.E. 2003. Reliability and validity of judgments of sound quality in elderly hearing aid wearers. *Ear and Hearing,* 24, 4–11.

Noble, W. and Gatehouse, S. (2006). Effects of bilateral versus unilateral hearing aid fitting on abilities measured by the Speech, Spatial, and Qualities of Hearing scale (SSQ). International *Journal of Audiology,* 45, 172–181.

Ricketts, T. (2000). The impact of head angle on monaural and bilateral performance with directional and omnidirectional hearing aids. *Ear and Hearing,* 21, 318–329.

Skafte, M. D. (2000). The 1999 hearing instrument market – the dispenser's perspective. *Hearing Review,* 7, 8–40.

Strom, K. E. (2006). The HR 2006 dispenser survey. *Hearing Review,* 13(6).

Studebaker, G.A. (1985) A "Rationalized" Arcsine Transform. *Journal of Speech and Hearing Research,* 28, 455–462.

Valente, M. & Mispagel, K.M. (2008). Unaided and aided performance with a directional open-fit hearing aid. *International Journal of Audiology,* 47, 329–336.

Walden, B.E., Demorest, M.E., Hepler, E.L. (1984). Self-report approach to assessing benefit derived from amplification. *Journal of Speech and Hearing Research,* 27(1), 49-56.