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Effectiveness of Directional Microphones and Noise Reduction Schemes in Hearing Aids: A Systematic Review of the Evidence

Ruth A. Bentler*

Abstract

A systematic review of the literature was undertaken to find evidence of real-world effectiveness of directional microphone and digital noise reduction features in current hearing aids. The evidence was drawn from randomized controlled trials, nonrandomized intervention studies, and descriptive studies. The quality of each study was evaluated for factors such as blinding, power of statistical analyses, and use of psychometrically strong outcome measures. Weaknesses in the identified studies included small sample size, resultant poor power to detect potentially worthwhile differences, and overlapping experimental conditions. Nine studies were identified for directional microphones, and the evidence (albeit weak) supports effectiveness. Two studies were identified for the noise reduction feature, and the evidence was equivocal. For the researcher, such a systematic review should encourage the careful consideration of appropriate methodologies for assessing feature effectiveness. For the clinician, the outcomes reported herein should encourage use of such a systematic review to drive clinical practice.

Key Words: Clinical trial, directional microphones, dual microphones, field trial, hearing aids, noise reduction, outcomes, questionnaires, satisfaction, self-report

Abbreviations: APHAB = Abbreviated Profile of Hearing Aid Benefit; AV = Aversiveness (subscale); BN = Background Noise (subscale); PHAB = Profile of Hearing Aid Benefit; SADL = Satisfaction with Amplification in Daily Life

Sumario

Se realizó una revisión sistemática de la literatura para encontrar evidencia del mundo real sobre la efectividad del micrófono direccional y de los rasgos digitales de reducción de ruido en los auxiliares auditivos actuales. La evidencia se obtuvo de estudios aleatorios controlados, de estudios de intervención no aleatorios, y de estudios descriptivos. La calidad de cada estudio fue evaluada con relación a factores como diseño ciego, poder de análisis estadístico y el uso de medidas de resultados psicométricamente fuertes. Las debilidades en los estudios identificados incluyeron muestra de pequeño tamaño, pobre poder para detectar diferencias potencialmente meritorias, y condiciones experimentales traslapadas. Se identificaron nueve estudios para micrófonos direccionales, y la evidencia (aunque débil) apoya la efectividad. Se identificaron dos estudios para el rasgo de reducción de ruido, y la evidencia fue ambigua. Para el investigador, tal revisión sistemática debería estimular

*Department of Speech Pathology and Audiology, University of Iowa, Iowa City, IA

Ruth A. Bentler, PhD, Department of Speech Pathology and Audiology, University of Iowa, Iowa City, IA 52242; Phone: 319-335-8723; E-mail: ruth-bentler@uiowa.edu

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una cuidadosa consideración de las metodologías necesarias para evaluar la efectividad de dichos rasgos. Para el clínico, los resultados reportados aquí deberían estimular el uso de dichas revisiones sistemáticas para orientar la práctica clínica.

Palabras Clave: Estudio clínico, micrófonos direccionales, estudio de campo, auxiliares auditivos, reducción del ruido, resultados, cuestionarios, satisfacción, auto-reporte

Abreviaturas: APHAB = Perfil Abreviado de Beneficio del Auxiliar Auditivo; AV = Rechazo (sub-escala); BN = Ruido de Fondo (sub-escala); PHAB= Perfil de Beneficio del Auxiliar Auditivo; SADL = Satisfacción con la amplificación en la Vida Diaria

In the United States there are estimated to be 23–28 million people with hearing loss. To this end, many technological advances have taken place over the past 20 years with the explicit goal of improving the communication ability of those individuals with reduced auditory capacity. However, the data suggest that both use time and satisfaction levels are not significantly rising. Kochkin (2000) reports that 18% of people who own hearing aids never wear them, 17% return the devices, and 20% cite dissatisfaction with them. A frequently stated complaint of the hearing aid user is difficulty understanding speech in a background of noise. Currently, hearing aids are implemented with various clinical strategies and circuitry schemes imposed in an attempt to improve speech understanding both in quiet and noisy environments. These include: binaural amplification, reduction of low-frequency amplification, compression amplification, directional microphones, and digital noise reduction. The purpose of this paper is to review the current literature for evidence of real-world effectiveness of directional microphones and noise reduction schemes.

DIRECTIONAL MICROPHONES

Directional microphones were first developed for use in the recording/broadcasting industry (Bauer, 1942). By the late 1960s, directional microphone hearing aids reached the European market (Arentsschild and Frober, 1972; Nielsen, 1972a, 1972b; Mueller, 1981) and, by the early 1970s, the U.S. market (Mueller, 1981; Ricketts, 2001). For the next 20 years, the literature was replete with studies overviewing the function and benefit for hearing aid use (Arentsschild and Frober, 1972; Lentz, 1972; Nielsen, 1972a, 1972b; Frank and Gooden, 1973; Carlson and Killion, 1974; Preves, 1974; Sung et al, 1975; Nielsen and Ludvigsen, 1978; Mueller and Johnson, 1979; Knowles Electronics, 1980; Hillman, 1981; Mueller, 1981; Madison and Hawkins, 1983; Hawkins and Yacullo, 1984). The directional microphone declined in use throughout the 1980s and into the early 1990s (Ricketts and Dittberner, 2002), due, in part, to the increased use of in-the-ear style hearing aids (Rumoshovsky, 1977). As components became miniaturized and algorithms for manipulating the "lobes" and "nulls" for use in head- and ear-worn devices have become more sophisticated, directional microphone use is increasing again (Killion et al, 1998; Ricketts and Dittberner, 2002).

In the early 1990s, a two-microphone directional hearing aid was developed and commercialized. Studies related to this new scheme showed excellent directional benefit in artificially contrived noise environments (e.g., Valente et al, 1995, 1999). This reemergence of the directional microphone in hearing aids has also led to the market release of a number of processing schemes, including adaptive directivity, programmable polar patterns, and frequency specific directivity. The data have consistently shown that directional microphone hearing aids *can* improve the signal-to-noise ratio (SNR) for listeners, dependant upon the number and placement of speakers; the type, level and distance of the noise source; the reverberation characteristics of the environment; and the amount of low-frequency compensation provided (for excellent reviews, refer to Amlani, 2001; Ricketts and Dittberner, 2002). Since the data for many of the studies to date have been obtained under contrived laboratory conditions, the resultant evidence supports the *efficacy* of the feature. Of greater concern to the practicing clinician is the *effectiveness* of those same designs in real-world environments.

A number of investigators have attempted to relate laboratory performance to subject demographics and self-report data (Ricketts and Mueller, 1999; Novick et al, 2001; Cord et al, 2002; Ricketts and Hornsby, 2003; Walden et al, 2003; Cord et al, 2004; Dhar et al, 2004; Walden and Walden, 2004; Walden et al, 2004). Ricketts and Mueller (2000) examined three studies in an attempt to relate the slope of the hearing loss, the amount of high-frequency hearing loss, and omnidirectional performance to laboratory-measured directional advantage. In one study, they noted a significant *negative* relationship between aided omnidirectional performance and directional advantage, as measured in a laboratory setting. Walden et al (2003) attempted to relate laboratory performance of speech perception in noise to field ratings of speech understanding in noise. No relationship was found. A similar lack of relationship was noted when the Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox and Alexander, 1995) measures were compared for two groups of subjects deemed "successful" and "unsuccessful" users of directional microphone hearing aids (Cord et al, 2002).

Despite the voluminous body of research supporting the efficacy of the various designs, it remains unclear how persons using hearing aids with a directional microphone view their success in their own environments. For the purpose of extracting evidence to support the clinical recommendation of hearing aids with that added feature, the following question was posed for systematic review: *"Do experienced/trained users of hearing aids with directional microphones report better amplification outcomes in daily life than users of hearing aids without directional microphones?"*

Specific key words used to identify related studies included "hearing aids," "self-report," "directional microphones," "dual microphones," "outcomes," "questionnaires," "satisfaction," "field trials," and "clinical trials." Key words that were believed to restrict the results to a particular comparison, or a particular population, were not included. Searches were undertaken using the following databases and/or engines: MEDLINE, ComDisDome, and the Cochrane Database of Systematic Reviews. In addition, investigators involved in current research with directional microphones were contacted for possible oversights.

In excess of 500 relevant studies were initially identified from the searches. Studies were retrieved for more detailed analysis if they met the following criteria:

- Published in a peer-reviewed journal
- Blinded (single or double), if appropriate to the design
- Used self-report outcome measures following field trials of directional and omnidirectional modes of hearing aid use

Factors of age, gender, length or type of previous hearing aid use, and microphone design were not considered to be exclusionary, although presentation of those demographics was considered to be integral to the quality rating of the study. Studies were excluded from the review if they involved pediatrics, multiple disabilities, cochlear implants, and middle ear implants. Study quality was assessed using the following criteria (Taylor et al, 2001):

- Was there an adequate description of the method of randomization (or counterbalance);
- Was there blinding of the subjects, the outcome assessor, or both?
- Was there a description of the total number of subjects recruited for the study, as well as the dropouts?
- Was a prestudy power analysis performed (such that the sample size was sufficient to detect any clinically significant differences)?
- Were psychometrically strong outcome measures implemented?

RESULTS OF SYSTEMATIC REVIEW OF DIRECTIONAL MICROPHONE EFFECTIVENESS

A total of nine studies were accepted for the subsequent review. The summary of each study's purpose, design, population, and

Table 1. Directional Microphone Articles

Study	Purpose	Subject (n)	Design	Tools/Outcomes	Strength
Boymans and Dreschler (2000)	To measure the effects of two noise reduction concepts: active noise reduction and directional microphones, separately and in combination.	16	Single blinded Within subject Crossover	APHAB EC, RV: D = O BN, AV: D > O	+
Cord et al (2002)	To explore the use pattern and benefit of switchable (omnidirectional and directional) microphone technology in real world.	44–48	Descriptive study	APHAB All subscales: D > O Use: D < O Overall satisfaction D = O	+
Gnewikow and Ricketts (2005)	To measure directional benefit in real-world settings (both laboratory and self-report) and the relationship between degree of hearing loss and directional benefit.	105	Double blinded Between groups	PHAB (no group effect) All subscales: D = O SADL (no group effect) Global: D = O Service and Cost: D > O Preference Quiet: D > O mild group only Noise: D > O mild group only Overall: D > O mild group only	+
Palmer et al (2005)	To evaluate self-reported benefit of second-order directional microphone (fixed and adaptive) and omnidirectional modes.	49	Single blinded Within subject	Ratings: D = O Preference: D = O	=
Preves et al (1999)	To evaluate the directional performance of an ITE hearing aid with wearer-selectable omnidirectional/directional operating modes.	10	Single blinded Within subject	**Exp 1** APHAB EC, BN, AV: D = O RV: D > O Preference: 6/10 D **Exp 2** APHAB EC, AV: D = O BN, RV: D > O Preference: 6/10 D	+
Ricketts et al (2003)	To examine hearing aid benefit as measured by speech recognition and self-assessment methods across omnidirectional and directional hearing aid modes.	15	Single blinded Within subject	PHAB: D + O > O Journal *SF: D > O **SBL: D < O	+
Surr et al (2002)	To identify characteristics of everyday listening situations that influence user preferences for omnidirectional versus directional hearing aid microphones.	11	Within subject Crossover	PHAB: D = O Journal: D = O	=
Walden et al (2000)	To determine preferences of hearing-impaired listeners for the omnidirectional versus the directional mode in everyday listening situations.	40	Single blinded Within subject	Field Ratings Speech understanding: D = O Comfort: D + NR > O Sound quality: D = O	=
Yueh et al (2001)	To compare the effectiveness of an assistive listening device, a nonprogrammable nondirectional microphone hearing aid, with that of a programmable directional microphone hearing aid against the absence of amplification.	60	Single blinded Between groups	HHIE: D > O Use time: D > O Willingness to pay: D > O	+

Note: D = directional; EC = ease of communication; HHIE = Hearing Handicap Inventory for the Elderly; NR = noise reduction; O = omnidirectional; RV = reverberant environments; SF = sounds in front; SBL = sounds from back and localization; "+ +" = strongly support; "+" = support; "=" = equivalent findings; "-" = not support; "- -" = strongly not support.

outcome is shown in Table 1. A summary of study quality is shown in Table 2. Given the limited number of studies that met the criteria, and the different procedures and outcomes measures used, it was not possible to pool findings. The outcome of each study, therefore, was evaluated regarding strength of support for the use of the directional microphone mode in hearing aids (refer to the final column in Table 1).

Across the nine studies, six used the Profile of Hearing Aid Benefit (PHAB; Cox and Rivera, 1992) or APHAB (Cox and Alexander, 1995) for extracting self-report outcomes. In addition, the following outcome measures were used (in one or more):

- use time (two)
- diaries/preference (four)
- field ratings (two)
- satisfaction (two)
- decrease in handicap (one)
- willingness-to-pay estimates (one)

Use of the PHAB or APHAB requires the completion of trials for both omnidirectional and directional use by the same subject. It remains unclear whether the subjects should have access to their earlier responses (from the first of the counterbalanced conditions) prior to reporting the outcome of the second condition. The studies reported here did not control for that, or did not report the control used.

In general, the directional mode resulted in more benefit (or fewer reported problems) for the different subscales of the PHAB and/or APHAB. Four of the six studies using those inventories showed that one or more subscale indicated either reduced communication problems or increased benefit with the directional mode. Cord et al (2002) found fewer reported problems (higher "frequency of success") on all subscales. For Ricketts et al (2003), the switchable mode (directional plus omni switch) was the only condition that resulted in more benefit for the Background Noise (BN) subscale. Preves et al (1999) also evaluated both directional and omnidirectional modes using a switchable device; although the directional mode resulted in higher average benefit for each of the subscales, only the difference on the AV (Aversiveness) subscale was statistically significant. Boymans and Dreschler (2000) also noted a reduction in reported problems on the AV subscale. Using a sign test, positive effects were also reported for three questions from the BN subscale: in car noise ($p < 0.05$), in conversation with one person or at dinner with several people ($p < 0.01$), and for conversation in a crowd ($p < 0.01$).

Use time did not provide evidence of mode superiority. One study (Yueh et al, 2001) reported more use of the directional condition, with an average of 8.8 hr./day for the directional hearing aid group compared to an average of 6.9 hr./day for the omnidirectional hearing aid group. In sharp contrast, Cord et al, 2002, noted their participants reported *using* their

Table 2. Summary of Study Quality for Directional Microphone Review

Study	Randomization procedures	Blinding	Follow-up ≥80%	Power calculation	Validated outcomes
Boymans and Dreschler (2000)	√	S	√	X	√
Cord et al (2002)	NA	NA	√	X	√
Gnewikow and Ricketts (2005)	NA	D	X	√	√
Palmer et al (2005)	NA	S	√	√	X
Preves et al (1999)	√	S	√	X	√
Ricketts et al (2003)	√	S	√	X	√
Surr et al (2002)	√	S	√	X	√
Walden et al (2000)	NA	S	√	X	X
Yueh et al (2001)	**	X	√	X	√

Note: √ = criterion met; X = criterion not met; NA = not appropriate to the design; S = single blinding; D = double blinding; ** = partial randomization (for two treatments only).

omnidirectional mode 77.7% of the time and their directional mode only 22.3% of the time. The different designs of the two studies make those results difficult to compare. The subjects in Yueh et al were *either* wearing a switchable directional microphone hearing aid or an omnidirectional microphone hearing aid; it is unclear as to the amount of time the hearing aid was in the directional mode. Cord et al reported on the amount of time the directional mode was implemented.

Evaluating user preference indicates a slight advantage for the directional mode in several studies. Gnewikow and Ricketts (2005) found no difference in preference across three groups of subjects varying in configuration of hearing loss: The directional mode was preferred in quiet environments, noise backgrounds, and overall. Preves et al (1999) found a preference for the directional mode for six out of ten subjects for each of two experiments (using compensated and noncompensated low-frequency response). Palmer et al (2005) had their 49 subjects keep a journal of experience and preferences. Their results indicated an equal number of participants preferred the omnidirectional mode to the directional mode, and an equal number did not have a preference. Walden et al (2000) used field ratings to infer preference. For speech understanding and sound quality, the results were equivocal; for sound comfort, the directional mode (but with the noise reduction feature activated) was more favorably rated. If journal entries can be interpreted as evidence of preference, Surr et al (2002) noted that all 11 subjects reported difficulty perceiving differences in the two programs (omnidirectional and directional modes); the general impression reported was that "both programs performed equally well in most situations" (2002, p. 315).

Satisfaction with directional microphones was assessed using an overall scale (in Cord et al, 2002) or by use of the Satisfaction with Amplification in Daily Life (SADL) inventory (Gnewikow and Ricketts, 2005). The SADL was designed to be used as a global measure and across four subscales: Positive Effect, Service and Cost, Negative Features, and Personal Image (Cox and Alexander, 1999, 2001). Cord et al (2002) found equal overall satisfaction across 48 subjects for the two microphone modes, even though most of the subjects reported using the directional mode "much less frequently" than the omnidirectional mode. Gnewikow and Ricketts (2005) found similar satisfaction levels for the two modes across three groups of subjects varying in degree of hearing loss, except for the Service and Cost subscale. On that portion of the inventory, the directional mode was rated better than the omnidirectional mode by all three groups of subjects (total n = 105).

Yeuh and colleagues (2001) used the Hearing Handicap Inventory for the Elderly (Ventry and Weinstein, 1982) self-report of handicap (activity limitation) in their investigation. Although the outcome indicated less handicap in the directional hearing aid group, it was difficult to divorce other potential benefits that may have impacted the results because the two groups were not using the exact same circuit for comparison. The directional microphone hearing aid allowed for user switching to the omnidirectional mode, utilized a remote-control option, and provided access to three memories of operation. In that same investigation, the subjects using the directional microphone hearing aids indicated willingness to pay significantly more of their monthly salary for the circuit than were those subjects using the omnidirectional hearing aids. Again, one cannot assume the two groups of hearing aid users were equally fit in other dimensions (e.g., gain, output, compression characteristics) since the circuits were different.

NOISE REDUCTION

Although hearing aids with noise reduction schemes were first promoted as solutions to speech understanding and comfort in noise 20 years ago, the early data did not support the contention (e.g., Bentler et al, 1993a, 1993b; Van Tasell et al, 1988). The original analog-based schemes included a user-switchable low-tone filter, the adaptive filter (e.g., Manhattan™ circuit by Argosy), adaptive compression™ (patented by Telex), and even low-frequency compression (ASP originally by Siemens). It was determined at the outset of this systematic review that noise reduction schemes (and evidence) published prior to 1995 would not be considered. Rather, the current digitally implemented noise reduction schemes using (primarily) modulation-based algorithms would be the focus of the review. In current

Table 3. Noise Reduction Articles

Study	Purpose	Subject number (n)	Design	Tools/Outcomes	Strength
Boymans and Dreschler (2000)	To evaluate the effectiveness of two noise reduction schemes (adaptive noise reduction and directional microphones) separately and in combination	16	Single blinded Within subject Crossover	APHAB All subscales: NR = No NR Specific items in AV subscale Speech recognition in car noise: NR > No NR Aversiveness for sudden loud sounds: NR > No NR Traffic noises: NR > No NR	=
Walden et al (2000)	To compare the performance of the GN ReSound digital BZ25 (omnidirectional, directional and noise reduction modes) to linear and WDRC processors	40	Single blinded Within subject Crossover	Field ratings Speech understanding: NR + D = D = O Sound comfort: NR + D > O Sound quality: NR + D = D = O	=

Note: D = directional; O = omnidirectional; NR = noise reduction; "+ +" = strongly support; "+" = support; "=" = equivalent findings; "-" = not support; "- -" = strongly not support.

schemes, each manufacturer has control over the algorithm function; that is, the number of channels of operation, the time constants, the magnitude of gain reduction as a function of frequency, and the "sensitivity" of the algorithm to the ratio of modulated and unmodulated inputs differ (Dreschler et al, 2001). As a result, the actual impact of the scheme on different inputs varies significantly from manufacturer to manufacturer (Bentler, 2003). With this variability in mind, it was determined that the focus of this systematic review would be self-reported evidence that any of these schemes were useful in some manner to the hearing-impaired hearing aid user. Specifically, the following question was posed: *Do users of digital noise reduction schemes currently implemented in wearable hearing aids report better amplification outcomes in daily life than users of hearing aids without noise reduction?*

As was the case for directional microphone technology, the evidence was obtained from field trials using self-report inventories as outcome measures. Specific key words used to identify related studies included "hearing aids," "self-report," "noise reduction," "questionnaires," "satisfaction," "field trials," and "clinical trials." Searches were undertaken using the following databases and/or engines: MEDLINE, ComDis Dome, and the Cochrane Database of Systematic Reviews. In addition, investigators involved in research of noise reduction schemes were contacted for possible oversights. Studies were retrieved for more detailed analysis if they met the following criteria:

- Published in a peer-reviewed journal
- Blinded (single or double), if appropriate to the design
- Used self-report outcome measures following field trials of hearing aids with and without the noise reduction feature

Although a larger number of studies were first identified (119) by the combination of searches, only two were accepted for the subsequent review. Those rejected were laboratory-based studies, clinical trials without blinding, or reports of prototype designs. The summary of each study's purpose, design, tools, and outcomes is shown in Table 3. The outcome of each study was evaluated regarding strength of support for the use of the noise reduction in hearing aids (refer to the final column in Table 3). Study quality was assessed using the same criteria as were applied to the directional microphone review (Taylor et al, 2001). That summary is shown in Table 4.

RESULTS OF SYSTEMATIC REVIEW OF NOISE REDUCTION EFFECTIVENESS

It is apparent from the tables that we currently have little access to evidence concerning the digital noise reduction feature, and the evidence at hand requires some

Table 4. Summary of Study Quality for Noise Reduction Review

Study	Randomization procedures	Blinding	Follow-up ≥ 80%	Power calculation	Validated outcomes
Boymans and Dreschler (2000)	C/T	S	X	X	√
Walden et al (2000)	C/T	S	X	X	X

Note: √ = criterion met; X = criterion not met; C/T = can't tell; S = single blinding; D = double blinding.

interpretation. Boymans and Dreschler (2000) combined three field trials of four weeks each with subsequent laboratory experiments for *both* features, directional microphones and noise reduction. Sixteen subjects completed the APHAB after four weeks use of the directional microphone feature and four weeks use of the noise reduction feature, counterbalanced across subjects. Although the effects of the noise reduction were not significant for any of the four APHAB subscales, several questions within the subscales showed significance in favor of the noise reduction feature for loud and/or aversive situations (refer to Table 3).

Walden et al (2000) assessed three experimental conditions on their 40 subjects: (1) omnidirectional, (2) directional, and (3) directional with noise reduction. The study was included in the review because it did allow a comparison of the noise reduction feature against two conditions without noise reduction. Their field ratings were obtained using 11-point semantic differential scales for three conditions of speech understanding (quiet, reverberant, and background noise), two conditions of sound comfort (nonspeech sounds and speech in background noise), and two conditions of sound quality/naturalness (sounds of nature and speech in background noise). The only significant finding was for the sound comfort ratings, wherein the noise reduction *plus* directional microphone mode resulted in higher ratings than did the omnidirectional mode. (The directional mode alone was not significantly different from either of the other two modes). Because the outcome for the noise reduction feature is confounded by the addition of the directional microphone feature, the data cannot be used to support the effectiveness of noise reduction alone.

A number of studies that did not meet the search criteria still provide information for consideration and possible insight into future research design. In one study, for example, subject estimates of annoyance and aversiveness were reported to be worse with the hearing aid (and noise reduction feature maximized) than without it. Palmer et al (2005) compared ratings after several weeks of experimental hearing aid use to the subjects' own ratings prior to using the new amplification and to ratings of subjects with normal hearing. Their results suggest that a properly fit hearing aid with the noise reduction feature will not reduce annoyance or aversiveness or even maintain this perception as compared to prefitting results. In that investigation, the carefully fit amplification system created, on average, a normal perception of annoyance and aversiveness. The authors caution that measures for many dimensions of sound quality may appear to degrade relative to the unaided performance due to increased audibility. They considered normal listeners' performance in the same environments to provide a better comparison to the aided performance than unaided versus aided measures.

Another study not included had the appropriate design (single-blinded crossover field trials of noise reduction "on" versus noise reduction "off"), but all of the outcome measures were obtained in the laboratory setting (Alcantara et al, 2003). Sentence reception thresholds (SRTs) were obtained in the presence of four different types of background noise, a measure that could only be obtained in the calibrated environment. Unfortunately, subject ratings following field trials for "comprehension," "listening effort," "sound quality," "sound clarity," and "listening comfort" were also obtained in the laboratory while the subjects listened to running speech in the same four noise backgrounds. Adequate blinding, counterbalancing of conditions, and multiple judgments supported the design of the study; however, the stimuli were not from the field trial experiences, and, therefore, the results are not included in this review.

Still another study was excluded from

consideration because of the blinding requirement. Boymans et al (1999) conducted a clinical trial of a digital ITE circuit with the adaptive noise reduction feature across 27 subjects. The control condition ("without noise reduction") was a conventional (analog) linear hearing aid. Although there is evidence to support the assumption of "no difference" across the digital (experimental) and analog (control) processors (Bentler et al, 2003), thus attributing any measured difference to the noise reduction feature of the experimental hearing aid, the absence of blinding negated the usefulness of the self-reported data.

DISCUSSION

These two critical reviews were undertaken to find real-world evidence of directional microphone and noise reduction effectiveness. The evidence supports the use of directional microphones, albeit modestly. The evidence remains equivocal for the noise reduction feature, in that only three individual items of one APHAB subtest (AV) supported the effectiveness of that feature. In that same study, the authors conclude that there was no extra benefit from the combined use of directional microphones and noise reduction over directional microphones alone (Boymans and Dreschler, 2000), further diffusing the weak supporting data.

Although there exists a large body of evidence indicating that listeners fit with directional microphone hearing aids obtain better speech recognition in many laboratory settings, further research is necessary to determine the extent to which that benefit can be generalized to real-world situations. The fact that many studies indicated equal support for the omnidirectional and directional modes suggests that one mode may not be superior for all environments. To this end, Walden and colleagues have addressed the issue of directional benefit in a slightly different manner. Rather than attempting to prove that one of the two modes (directional *versus* omnidirectional) is better, they have attempted to ascertain the environments in which trained users of directional microphone hearing aids prefer to use the directional versus omnidirectional modes (Surr et al, 2002; Walden et al, 2003; Walden and Walden, 2004). That direction in research precludes the use of *blinding* in favor of *training*, an interesting approach to understanding subjective response to the two microphone modes. Of particular interest is the recent emergence of a model delineating those environments in which directional microphones are the chosen mode of operation (Cord et al, 2004). Such a model may prove useful for algorithm development.

The question of noise reduction effectiveness remains a challenge for researchers. There have been a number of marketing claims of improved speech perception, better sound quality, and improved listening ease; however, the sources of those claims were not within the inclusion criteria of this systematic review. Although the ultimate goal of future noise reduction algorithms continues to be in the realm of improved speech perception ability for the hearing-impaired listener, any improvement in sound quality, or sound comfort, as indicated in this critical review, could be interpreted as providing improved communication for the hearing aid user.

The field of audiology has not seen a significant number of large randomized controlled trials (RCTs) in any realm of treatment efficacy. Instead, the designs are often contrived, the subjects often do not constitute a random sample of the population in question, and the power of the statistical analysis is often weak. As is evident in Tables 2 and 4, none of the studies included in this systematic review met each of the quality criteria. The "Jadad scale" has been widely used to assess the quality of clinical trials (Jadad et al, 1996). The scale is composed of five questions: (1) Is the study randomized? (2) Is the study double blinded? (3) Is there a description of withdrawals? (4) Is the randomization adequately described? (5) Is the blinding adequately described? Originally, the scale was applied to trials describing pain treatment but has been expanded to include other areas, including hearing aid trials (Taylor et al, 2001). A Jadad score was not calculated in the tables of study quality, yet it is apparent that these five domains of study quality were not adhered to in the hearing aid research reviewed here. Only one study represented a randomized controlled trial (Yueh et al, 2001); the more common design is to use randomized crossover trials, wherein each subject receives both or all treatments with a counterbalancing of the order among subjects. Other aspects of study quality indicated in Tables 2 and 4 include power calculation and validated outcomes. Without sufficient sample size, for example, it is unlikely that the statistical analysis will have the power necessary to detect clinically significant differences across groups or conditions being studied. Since low power is a major cause of false conclusions, understanding and utilizing methods to increase the power of the statistical analyses remains a challenge for the audiology researcher.

Only one of the studies described in this review was double blinded in design, another typical characteristic of hearing aid research. Instead, the studies were single blinded, if appropriate to the question; that is, only the subjects are unaware as to the condition being investigated. It has long been established that single (or preferably double) blinding is necessary in studies aimed at determining the effectiveness of new technologies (Bentler et al, 2003). Without such controls, it cannot be known whether the benefits measured are due to a real underlying benefit, or to the subject's preconceived notion about the value of the treatment under investigation. In assessing the potential benefits of directional microphones, however, there is emerging evidence that training is necessary for optimizing the effectiveness (Walden et al, 2000; Cord et al, 2002). Since there already exists a large body of literature acknowledging the *efficacy* of the designs (i.e., they do work in contrived laboratory settings), perhaps our research focus now should be on maximizing that benefit through training. Such design would preclude blinding of the subject as to the condition under investigation.

CONCLUSION

This systematic review was undertaken to support the clinical application of directional microphones and digital noise reduction schemes in hearing aids. Based on the data reviewed herein, directional microphones offer additional advantage over amplification alone. That advantage appears to be optimized by both a user-controlled switch and training regarding environment-specific use. The noise reduction feature, with all the various manufacturer-specific implementations, shows a modest inclination toward improved listening ease in select environments. More studies specifically designed to address that feature are necessary before its effectiveness is understood and the results are conveyed to the clinical population.

For the researcher, such a systematic review should encourage considerations in methodology related to design, power analyses, and more straightforward approaches to assessing effectiveness. With an increased sensitivity to the issues involved in generating valid and reliable evidence, the researcher should be able to provide more straightforward direction for the clinician aiming toward evidence-based clinical practices.

For the clinician, the results should encourage both the process of systematic and critical review as well as the emerging evidence for hearing aid feature effectiveness. Relying on carefully controlled research outcomes to drive clinical practice makes the clinician more accountable to patients and third parties alike.

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