J Am Acad Audiol 19:657–671 (2008)

A Systematic Review to Determine the Effectiveness of Using Amplification in Conjunction with Cochlear Implantation

DOI: 10.3766/jaaa.19.9.2

Anne D. Olson*
Jennifer B. Shinn†

Abstract

Background: The question regarding the use of amplification with implantation is timely and relevant in today's clinical settings where an increased number of adults with measurable hearing are receiving cochlear implants due to the expanding implant criteria, especially among individuals seeking bilateral implantation.

Purpose: To review the evidence available to answer the clinical question: "Does amplification in the ear opposite of a cochlear implant provide improved communication function for adult users?"

Research Design: A systematic review of the evidence that met the search criteria related to the use of amplification in adult implant users. All types of experiments were included with the exception of expert opinion. This systematic review ranked the levels of evidence related to these studies and distinguished the levels of evidence from judgments about the grade and strength of recommendations for the stated clinical question.

Study Sample: Fifty-two articles were initially reviewed with a final 11 articles meeting the search criteria and identified for in-depth analysis.

Data Collection and Analysis: Several electronic databases and textbooks were searched to locate the evidence related to bimodal stimulation. Each article was reviewed using a check sheet and assigned a ranking for level of evidence (Levels 1–6) based on the type of research design that was used and a grade of evidence (A–D) based on the quality, relevance, and extensiveness of the study. Finally the level and grade were collapsed into only three categories to indicating the strength of the recommendations coming from each study and were classified as either strong (I), moderate (II), or weak (III).

Results: Several trends about bimodal stimulation were observed, which include (1) significantly better speech understanding in the bimodal condition for many participants; (2) in noise, the largest bimodal benefits in speech recognition; (3) variable findings on localization tasks; and (4) overall significant improvement in functional ability based on self-assessments. The preponderance of evidence received grades of B or C.

Conclusions: The evidence available indicates "moderate" (II) strength in support of bimodal stimulation for adult implant users. Clinicians should encourage their clients to consider bimodal fittings. Additional research is needed about optimal time frame for introducing bimodal fittings as well as establishing a clinical profile of patients who may benefit most from this intervention compared to bilateral implantation.

Key Words: Bimodal, cochlear implant, evidence-based practice, hearing aid, systematic review

Abbreviations: ADRO = adaptive dynamic range optimization; CANS = central auditory nervous system; CDSR = Cochrane Database of Systematic Reviews; CI = cochlear implant; CI + HA = cochlear implant with hearing aid; CINAHL = Cumulative Index to Nursing and Allied Health Literature; EBP = evidence-based practice; HA = hearing aid; ICF = International Classification of Functioning; ILD = interaural level difference; ITD = interaural timing difference; SNR = signal to noise ratio; WHO = World Health Organization

*Department of Rehabilitation Sciences, University of Kentucky; †Division of Otolaryngology-Head and Neck Surgery, University of Kentucky

Anne D. Olson, 900 S. Limestone #124J, Department of Rehabilitation Sciences, University of Kentucky, Lexington, KY 40536; Phone: 859-278-2224; E-mail: aolso2@uky.edu

This article was presented at the American Auditory Society Annual Meeting, March 2007, Scottsdale, AZ.

Sumario

Antecedentes: En asunto relacionado con el uso de amplificación junto a un implante coclear es oportuno y relevante en el contexto clínico actual, donde un número mayor de adultos con audición medible están siendo implantados debido a la ampliación de los criterios de colocación de implantes, especialmente entre individuos que desean una implantación bilateral.

Propósito: Revisar la evidencia disponible para contestar la pregunta clínica: ¿Aporta la amplificación en el oído opuesto a un implante coclear una función de comunicación mejorada para usuarios adultos?

Diseño de Investigación: Una revisión sistemática de la evidencia que cumplió con los criterios de investigación relacionados con el uso de amplificación en usuarios de implante coclear. Todo tipo de experimento fue incluido con excepción de la opinión de los expertos. Esta revisión sistemática categorizó los niveles de evidencia relacionados con estos estudios y distinguió dichos niveles de evidencia de los juicios sobre el grado y fortaleza de las recomendaciones para la mencionada pregunta clínica.

Muestra del Estudio: Se revisaron inicialmente cincuenta y dos artículos, hallando once artículos que finamente cumplían los criterios de búsqueda y se identificaron para un análisis a profundidad.

Recolección y Análisis de los Datos: Varias bases electrónicas de datos y libros se texto se investigaron para localizar la evidencia relacionada con la estimulación bimodal. Cada artículo fue revisado por medio de una hoja de registro y se le asignó una categoría según el nivel de evidencia (Niveles 1–6) con base en el tipo de diseño experimental que se utilizó y el grado de evidencia (A–D) según la calidad, relevancia y cuán exhaustivo fue el estudio. Finalmente, el nivel y el grado fueron conjuntados en tres categorías para indicar la fortaleza de las recomendaciones que emanan de cada estudio y se clasificaron como: fuerte (I), moderado (II) o débil (III).

Resultados: Se observaron varias tendencias sobre la estimulación bimodal, que incluyen: (1) Significativa mejor comprensión del lenguaje en la condición bimodal para muchos participantes; (2) los mayores beneficios en la condición bimodal en reconocimiento del lenguaje en medio de ruido; (3) hallazgo variables en tareas de localización; y (4) mejoría global significativa en la capacidad funcional, con base en auto-evaluaciones. La preponderancia de la evidencia recibió grados de B o C.

Conclusiones: La evidencia disponible indica una fortaleza "moderada" (II) en el apoyo de la estimulación bimodal en adultos usuarios de un implante. Los clínicos deberían instar a sus clientes a considerar la adaptación bimodal. Se necesita investigación adicional para establecer el rango de tiempo óptimo para introducir la adaptación bimodal, así como para establecer el perfil del paciente que podría beneficiarse más de esta intervención, comparado con la implantación bilateral.

Palabras Clave: Bimodal, implante coclear, práctica basada en evidencia, auxiliar auditivo, revisión sistemática

Abreviaturas: ADRO = optimización adaptativa del rango dinámico; CANS = sistema nervioso auditivo central; CDSR = Base de Datos Cochrane de Revisiones Sistemáticas; CI = implante coclear; CI + HA = implante coclear con auxiliar auditivo; CINHAHL = Índice acumulado de Literatura en Enfermería y Áreas de Salud Relacionadas; EBP = práctica basada en evidencia; HA = auxiliar auditivo; ICF = Clasificación Internacional de Funcionamiento; ILD = diferencias inter-auriculares de nivel; ITD = diferencias inter-auriculares de tiempo; SNR = tasa señal-ruido; WHO = Organización Mundial de la Salud

Historically, adult cochlear implant candidates presented with postlingual, profound, sensorineural hearing loss and poor speech recognition ability. As technology improves, candidacy for cochlear implantation has rapidly expanded to include individuals with less severe hearing losses (Cullen et al, 2004). Now, individuals with pre- or postlingual severe, sensorineural hearing loss, and some speech recognition ability are candidates. To date, most adults and children have received one implant and have obtained substantial benefits, including improved speech understanding, communication function, and quality of life (Hamzavi et al, 2003; Castro et al, 2005). Monaural listeners may present with unique listening difficulties, especially in noise and when localizing sound (Bronkhorst and Plomp, 1988; Boothroyd, 2006). One treatment approach for these individuals is to use a conventional hearing aid in the nonimplanted ear, which is often called bimodal stimulation. Many current implant candidates present with some residual hearing in at least the better ear and have relied on amplification for many years; however, it is unclear if they should continue using amplification opposite their implant or rely on the implant alone. Furthermore, it is unknown how well the auditory system can adapt to incongruent (electric and acoustic) stimulation coming from different ears. In some cases, this treatment approach may actually be contraindicated. The purpose of this paper is to further explore how effective bimodal stimulation is for adults by conducting a systematic review of the evidence.

Bimodal stimulation is defined as electrical stimulation to the implanted ear with acoustic stimulation to the opposite ear by using traditional amplification (Clark, 2003). Bimodal stimulation is most common in individuals with residual hearing and/or good performance with amplification in the nonimplanted ear (Offeciers et al, 2005). The potential benefit of this arrangement is that high frequencies will be enhanced with electric stimulation and lower frequencies will be enhanced with acoustic stimulation (Gantz and Turner, 2003). Although access to high frequency information is critical to speech perception, lower frequencies may be equally important to improved understanding in background noise (Qin and Oxenham, 2003). Therefore individuals seeking improved understanding of speech in noise may benefit from a bimodal fitting. Bimodal stimulation may be of particular benefit for recipients seeking improved music perception since acoustic signal processing is more efficient at encoding music than currently available electrical signal processing strategies (Kong et al, 2004). Although potential advantages of bimodal stimulation have been identified, challenges remain for individuals to integrate the different bimodal inputs. Problems related to loudness balancing difficulties, "lags" in processing time from the cochlear implant compared to hearing aid, and an unnatural quality have all been reported when using bimodal stimulation (Blamey et al, 2000; Tyler et al, 2002).

The exact number of bimodal users is unknown. Tyler and colleagues (2002) reported that an estimated 10% of implant recipients use amplification in their contralateral ear based on a survey of individuals who were implanted between 1986 and 1999. Among adults with more residual hearing (thresholds better than 90 dB at 500 Hz), 50% of implant users reported using amplification in the opposite ear for at least a portion of the day (Cowan and Chin-Lenn, 2004). In the United States, recipients are typically counseled to only use their implant for the first three months so that the auditory system can adapt to novel electrical stimulation. A patient's history of previous unsuccessful hearing aid experience may also contribute to low bimodal rates. Clinicians and patients may assume that if patients did not benefit adequately from amplification prior to surgery, that they will not obtain any benefit after implantation. Regardless of the underlying explanation, the recommendation to not use amplification after implantation appears to be based on repeated clinical practice and not on an evidence-based review of the literature. As individuals with less severe hearing losses are implanted, increases in bimodal use may be observed. Therefore it is important for audiologists to understand the scope of bimodal amplification and develop profiles of individuals who may benefit the most from this practice. Several advantages that may contribute to improved communication function may be theorized for using amplification in the nonimplanted ear. These include enhanced listening opportunities and prevention of further auditory deprivation.

Hearing from two ears rather than one provides enhanced listening opportunities for listeners. Reports of this binaural advantage have been documented for more than 50 years and have included findings such as improved levels of localization and better hearing in noise (Hirsh, 1950; Carhart, 1965; Gelfand et al, 1987; Bronkhorst and Plomp, 1988; deJong, 1994). Moore (2003) provided an in-depth review on binaural hearing that describes how acoustic information arriving at each ear is encoded and activated in the central auditory system. In many real world listening conditions, sound often arrives at one ear before the other. The difference in acoustic information arriving between ears is widely known as the "head shadow effect." The head shadow effect causes changes in both the temporal and intensity cues available to each ear, which contributes to our localization ability. In addition, the head shadow effect is frequency dependent. Greater attenuation rates are observed for higher frequency compared to lower frequency sounds because of the shorter wavelengths associated with higher frequencies (Moore, 2003). Thus, both interaural timing difference (ITD) and interaural level difference (ILD) are acoustic cues that assist in localization. Although additional processes may be involved, ITD cues are used for localizing low frequency tonal stimuli, and ILD are used for localizing high frequency stimuli (Moore, 2003). Additionally, when speech and noise are present there is a more favorable signal-to-noise ratio (SNR) at one ear compared to the opposite ear allowing a listener to attend to the ear with the most favorable SNR (Bronkhorst and Plomp, 1988; Ching et al, 2005). Bronkhorst and Plomp (1988) reported a 2–3 dB improvement in the SNR for speech recognition ability in normal hearing listeners. A similar finding was reported in binaural hearing aid users compared to monaural hearing aid users (Festen and Plomp, 1986). Monaural stimulation prevents implant users from taking advantage of these binaural cues.

Another benefit of bimodal stimulation could be the prevention of additional negative effects related to auditory deprivation to the unaided ear (Gelfand et al, 1987; Silman et al, 1992). Silman and colleagues (1992) described this phenomenon in a case study of an adult with bilateral sensorineural hearing loss who used monaural amplification for treatment of a symmetrical hearing loss. Significant reduction in word recognition ability was observed in the ear without amplification. After a trial period with amplification in this ear, an improvement in word recognition ability was documented. More recently deprivation effects were evaluated in a large group of adults with asymmetric hearing loss over a two-year period (Silverman et al, 2006). Significant declines in word recognition ability were reported in the unaided ear, whereas declines were not observed in the aided ear. Together these findings suggest that the use of amplification in a nonimplanted ear may compensate for any negative effects related to further auditory deprivation.

When faced with challenging cases, clinical decision making in audiological settings may be based on initial training experience, shaped by current clinical practice patterns, and/or derived in part from consultation with colleagues. Practice guidelines from professional organizations are also useful in planning interventions, but oftentimes these do not address individual client needs. Recently, the use of evidence-based practice (EBP) has been widely adopted in medical settings to augment clinical practice. EBP is a process that practitioners can use to assist in clinical decision making by considering information from three sources: (1) the current evidence available relative to the clinical question(s); (2) the practitioner's clinical expertise; and (3) the values of the client and family (Sackett et al, 1996). The use of EBP is gradually migrating into a wide variety of rehabilitation settings to assist with clinical decision making (Lou, 2002). Implementation of EBP in audiology has been encouraged by professional organizations such as the American Academy of Audiology (Valente et al, 2006) and the American Speech-Language-Hearing Association (2004). Increased interest in this topic has generated EBP reviews of audiological interventions by several authors (Cox, 2005; Hawkins, 2005; Sweetow and Palmer, 2005).

EBP provides a method through which audiologists can stay informed about current research and can offer their patients information objectively about the effectiveness of interventions. Although EBP principles may not be used for every clinical question, clinicians can use this model when faced with complicated cases or in cases with which they have limited experience. By critically evaluating research, clinicians can also justify interventions for their clients who may be paying for services or for third-party payers. Through the use of EBP clinicians will be better able to evaluate the strength of existing evidence for specific interventions and identify effective treatment options for patients accordingly (Abrams et al, 2005). Ultimately, the use of EBP serves as a process that will improve the quality of services for clients.

The application and implementation of EBP to audiological settings has been thoroughly discussed by Cox (2005). She advocates a specific approach for applying EBP to clinical practice by using a five step procedure. The first step is to establish a clinical question to be answered. This step is important because it forces the clinician to identify the specific elements about the client (age, gender, etc.), the problem, the proposed intervention, and the outcome measures of interest (Lou, 2002). By identifying these critical elements, the clinician can efficiently conduct electronic searches to answer questions.

Secondly, the clinician should locate the best evidence available from data-based sources that catalogue peer-reviewed journals. Several systematic reviews on health-related topics are available through evidence-based research centers such as the Cochrane Database of Systematic Reviews (CDSR). The CDSR publishes results of intervention studies only and is managed by a non-profit, international collaborative group (Lou, 2002). Authors submit reviews that identify a specific intervention and determine whether or not the intervention is effective based on an extensive and systematic review of the literature. CSDR summaries allow anyone who reviews these articles to become familiar with the primary studies related to a specific intervention. The CDSR can be accessed through a university library electronic journal system; however, several abstracts are available at no charge through the Internet. If a systematic review is not available in the CDSR, then an individual systematic database search using key words related to the clinical question should be conducted. Examples of search engines that highlight audiology research are the Cumulative Index to Nursing and Allied Health Literature (CINAHL), PubMed, or MEDLINE (Abrams et al, 2005).

The third step is to evaluate the evidence so that strong research findings can be separated from less powerful research results. This step may be unfamiliar to many practicing audiologists; however, use of a critical review worksheet is an efficient mechanism to facilitate this process. A critical review worksheet lists important research components for readers to consider (i.e., participant selection, researcher bias, control groups, sample size, etc.) while reviewing articles. An example of a critical review sheet that was specifically designed for evaluating the effectiveness of clinical interventions (MacDermid, 2004) is located in Appendix 1. Interpretation guidelines for each research parameter are available to clarify how parameters should be analyzed. The fourth step is to decide on a recommendation(s) about the evidence by combining the clinician's expertise with the client's individual needs. This is where clinicians will need to make critical judgments about how the quality of the studies applies to their specific patient. The final step is to present the findings to the client and family so that a plan for intervention can be developed. Input from the

Table 1. Level, Grade, and Strength of Evidence Used to Rate Studies for Bimodal Stimulation (Valente et al, 2006)

Level	Number of experiments identified in this search	Criteria
1	0	Systematic Review/Meta-Analysis
2	0	RCT
3	4	Nonrandomized Intervention Study
4	4	Nonintervention (Cohort, Cross-Sectional)
5	3	Case Reports
6	excluded	Expert Opinions
Grade		**Criteria**
A	0	Level 1 or 2 with consistent conclusions
B	5	Consistent Level 3 or 4 or extrapolated evidence from Level 1 or 2 studies
C	3	Level 5 studies or extrapolated from evidence from Level 3 or 4 studies
D	3	Level 6 or inconsistent studies of any level that have high risk of bias
Strength		**Criteria**
I	0	Evidence is strong and is obtained from RCT or well-designed clinical studies. The recommendation is usually indicated, accepted, and considered effective and useful (Requires Grade A evidence)
II	9	Evidence is from clinical studies that were based on retrospective data analysis, clinical studies that were not randomized or carefully controlled. The recommendation is accepted and the weight of the evidence supports its use and effectiveness (Requires Grade B or C evidence)
III	2	Evidence is secondary because it is based on current or long-standing practice without substantial supporting basic or clinical data. The recommendation is acceptable, but its usefulness may be questioned

Note: RCT = randomized control trial.

client is a critical component to the EBP process so that their preferences and values can be incorporated into intervention options.

Based on the relevance and potential advantages of bimodal stimulation described earlier as well as the importance of including EBP in audiological decision making, a systematic review was conducted. Inherent to that design are two different purposes: (1) to discuss the methodology used in an EBP review and (2) to answer a clinical question of interest: "Does amplification in the ear opposite of a cochlear implant provide improved communication function for adult users?"

METHODOLOGY

Rating the Quality of Evidence

Rating the quality of research requires ranking studies to reflect those that are the most to the least credible. Several resources are available to help clinicians determine the strength of experimental studies. The ranking scale used in this study was outlined by the American Academy of Audiology's Task Force on Audiologic Management of Adult Hearing Impairment (Valente et al, 2006) and is illustrated in Table 1. The level of evidence (1–6) reflects the type of research design that was used. The grade of evidence (A–D) indicates how confident the practitioner views the quality, relevance, and extensiveness of data that are discussed. The strength of the recommendation is determined by considering both the level and the grade of the recommendation and is reflected in a rating of I–III. The better the grade, the more confident practitioners can be in the strength of the findings (Valente et al, 2006). Research findings from this multidisciplinary ranking system are ultimately collapsed into only three categories to indicate strong (I), moderate (II), or weak (III) recommendations. By doing so, the variability in quality of treatment studies becomes obscured. One way to address this issue is to review the articles for potential confounding variables and then tabulate findings. In a comprehensive systematic review of the health-related quality of life and hearing aids (Chisolm et al, 2007), a spreadsheet was used to assist in this task. An alternative method to quantify and assist in rating the quality of the studies is to use an evaluation tool (MacDermid, 2004) illustrated in Appendix A. This tool includes 24 items that reflect parameters that should be addressed in research studies such as power analyses, effect sizes, explanation of missing data, sampling, and retention rates. A maximum of 48 points is possible. Interpretive guidelines are also available to help reviewers in this scoring process. This quantitative rating scale was used in the present review to assist the authors in deciding about the quality of the articles on bimodal stimulation.

To conduct this systematic review, a variety of research designs for analysis were included: systematic reviews, random control trials, nonrandomized intervention (quasi-experimental), nonintervention descriptive designs (case control study, cohort study), and case report(s) (single or series). In addition, only articles in English were included for review. Excluded from review were expert opinion or consensus articles because this type of research provides minimum contribution to the overall body of evidence as discussed by Abrams and colleagues (2005). Of particular clinical interest to us were studies that used self-assessment tools as well as conventional speech perception measures that reflect functioning across different levels (based on International Classification of Functioning [ICF]) as encouraged by the World Health Organization (WHO, 2001). The WHO model highlights the importance of evaluating the consequences of a disability across multiple domains to better understand the impact of the impairment. Evaluating outcomes for hearing impairment should include measures of: (1) body structure and function, (2) activity, and (3) participation to reflect how individuals with communication disorders interact with their environment (Threats, 2006). For an in-depth discussion about how these dimensions apply to audiology, the reader is referred to Abrams et al (2005).

Search Strategy

No systematic review for this specific question was available through CDSR. Therefore, evidence was obtained through individual electronic databases (PubMed, CINAHL, and MEDLINE) as well as two textbooks (Gelfand, 1997; Clark, 2003) and non-peer-reviewed (trade) journals. The following key words were entered in the search fields to identify articles related to this clinical issue: "cochlear implant AND hearing aid AND adult." Additional terms were used in subsequent searches: "cochlear implant AND bimodal stimulation," as well as "cochlear implant AND contralateral hearing aid." Over 187 articles were initially identified with the above search description. Fifty-two articles were selected for a more comprehensive review based on the previously mentioned criteria. Forty-one of these articles were eliminated from in-depth review because they were: review articles, expert opinion, or not in English. This procedure yielded a final 11 articles for in-depth analysis. The distribution showing the type of evidence available for final review is summarized in Table 1. Each article was critically reviewed and assigned a rating for level, grade, and strength of the evidence.

EVALUATION OF EVIDENCE

Level, Grade, and Strength

A summary of the articles selected with their results for level, grade, and strength of evidence is illustrated in Table 2. No systematic reviews, meta-analyses, or random control trial studies were identified in this search. Three of the studies represented Level 5 evidence (Waltzman et al, 1992; Tyler et al, 2002; Kileny et al, 2004), four studies demonstrated Level 4 evidence (Armstrong et al, 1997; Hamzavi et al, 2004; Dunn et al, 2005; Morera et al, 2005), and four studies demonstrated Level 3 evidence (Ching et al, 2004; Ching et al, 2005; Luntz et al, 2005; Mok et al, 2006). No articles received grades of A, nor did any studies meet the criteria to receive the strongest recommendation (I) because no studies used a random control design. Three of the studies were assigned a D for grade of evidence (Waltzman et al, 1992; Tyler et al, 2002; Kileny et al, 2004) because each involved only two or three participants who were identified through convenience samples. Therefore, biases may exist in this selected population because participants may not be representative of the general population of implant users. Although these studies reflect some of the pioneering clinical research on the use of bimodal stimulation, the strength of recommendation from this evidence can only be judged as weak (III). Together, this group of studies suggests that although bimodal stimulation is an acceptable intervention for some individuals, its clinical usefulness may not be appropriate for all users. Three studies were assigned grades of C for their evidence because they demonstrated consistent findings but may have incorporated quasi-experimental designs where complete randomization was not achieved (Armstrong et al, 1997; Tyler et al, 2002; Hamzavi et al, 2004). Common problems in these studies were small sample sizes and ceiling effects, especially with the control groups of normal listeners. Almost half of the reports received grades of B and were judged to be highly consistent even though complete randomization was not achieved (Ching et al, 2004; Ching et al, 2005; Dunn et al, 2005; Luntz et al, 2005; Morera et al, 2005). The studies discussed above received a grade of B or C and were thus judged to reflect moderate strength (II) of recommendation. In addition, they demonstrated overall good quality research design, used appropriate statistical analysis, and revealed few methodological flaws. Together, this group of studies suggests that the recommendation of amplification with implantation provides adequate evidence to support its use.

Analysis of each study using the MacDermid (2004) scale and interpretive guidelines was also completed (Table 2). The mean raw score was 25 (SD = 7.11). This large range of scores (13–36) emphasizes the variability that exists within studies included in this review. As expected, a strong negative correlation ($r = -.89$) between the traditional levels of evidence (1–6) and the MacDermid Scale score (1–48) was found (Figure 1). Higher scores on the MacDermid Scale were associated with lower levels (reflecting higher quality) of evidence. This strong correlation suggests that use of the MacDermid Scale may be valuable for clinicians in critiquing experimental research. Additionally it provides a quantitative summary that reflects the variability of rigor frequently found among experiments.

Study Characteristics

Table 2 provides a summary of the research articles reviewed and their findings. Each experiment made unique contributions to our understanding of the potential benefits as well as variables that affect performance with bimodal stimulation. Below is a brief summary of the study characteristics of each article.

The role of residual hearing in the nonimplanted ear has been investigated by several authors. Waltzman et al (1992) described results from a case study in two adults with variable degrees of residual hearing. They concluded that thresholds in the nonimplanted ear and usage time can affect the outcome. Tyler et al (2002) described performance on speech perception and localization tasks from pilot data on three postlingually deafened adults. These preliminary findings suggested that bimodal stimulation was beneficial in quiet and noise for some participants but that integration may be affected by the preoperative performance levels of each ear. A retrospective study by Hamzavi et al (2004) examined a group of experienced postlingually deafened adults who were implanted in the poorer ear, leaving the better ear (mean PTA = 101 dB) for hearing aid use. Postoperative improvements were reported for all participants. In contrast, more variable performance on speech perception and localization tasks was reported by Dunn and colleagues (2005). Although many implant users obtained additional benefit from contralateral hearing aid use, some actually demonstrated poorer performance. They concluded that variables contributing to these findings may have been related to the amount of residual hearing, length of implant use, or amount of high frequency amplification.

Several researchers have compared performance in quiet and noise for postlingual populations. In a group study by Armstrong et al (1997), American and Australian listeners showed bimodal benefit in both quiet and noise. Greater binaural advantage in noise was observed compared to quiet. In a case study with two adults, Kileny and colleagues (2004) further explored bimodal effects in noise. Specifically they demonstrated a greater bimodal benefit when the noise was coming from the implanted side rather than from in front or from the hearing aid side. In a Spanish speaking population Morera and his colleagues (2005) reported improvement in word recognition scores in quiet from 64% in the CI (cochlear implant) alone condition to over 94% in the bimodal condition for all listeners. They also reported that the greatest binaural benefit was observed when noise was presented at the side of the implant and the hearing aid was in the contralateral ear.

The time course over which bimodal integration occurs has also been studied. In both pre- and postlingual adults, Luntz and colleagues (2005) demonstrated that by six months postoperative, mean sentence scores were 35% for the implant alone condition and 41% in the bimodal condition. In contrast, by 12 months postoperative, implant alone scores were 61% and 75% in the bimodal condition. This benefit was observed for nearly 60% of the participants.

The role of hearing aid settings was initially explored by Kileny and colleagues (2004). In their case study, no differences in speech recognition scores were reported for performance with narrow-band (low frequency) versus broad-band frequency emphasis hearing aid settings. Ching et al (2004) further investigated the role of hearing aid settings in a group of 21 new and experienced bimodal users. Specifically all hearing aids were set using an NAL-NL1 prescription. All listeners showed binaural benefits on at least one of three performance measures (words, sentences, or localization task). These strong findings led these researchers to recommend that bimodal use be a standard rehabilitative practice.

Research has also been conducted about possible mechanisms for the reported variable findings of bimodal benefit. It has been hypothesized (Mok et al, 2006) that one mechanism contributing to variable findings might be partially explained by conflicting information from the hearing aid and implant. In a prospective group study, they specifically measured high frequency hearing aid benefit above 2000 Hz in the nonimplanted ear. By using information transmission analysis (Miller and Nicely, 1955), Mok and colleagues calculated the amount of speech information from the hearing aid that was supplementary to the speech information from the implant and compared this to overall bimodal benefit. They found that participants with poorer aided thresholds in the mid to high frequencies actually demonstrated greater bimodal benefit. In a comparative study, Ching et al (2005) evaluated binaural redundancy and interaural timing cues in a population of normal hearing listeners, hearing aid users, and bimodal users. Binaural redundancy was measured by comparing SNR for 50% correct sentence identification with the implant alone compared to the bimodal condition. Interaural timing cues were assessed by comparing the SNR in the binaural condition both with and without a time delay of the noise. Ching and colleagues (2005) found that while normal hearing and hearing

Table 2. Summary of 11 Articles Identified through Electronic Search

Investigator(s)	Design	Age	Duration CIHA use	Onset of HL
Waltzman, Cohen, and Shapiro (1992)	Pre/post case series n = 2	Age: 29–49; Mean = 39	1 year	Postlingual
Tyler, Parkinson, Wilson, Witt, Preece, and Noble (2002)	Retrospective n = 3	Age: 53–64; Mean = 56.6	>5 years	Postlingual
Kilney, Snorrason, Zwolan, Macpherson, and Middlebrooks (2004)	Case study n = 2	Adults; not specified	Not specified	Not specified
Armstrong, Pegg, James, and Blamey (1997)	Prospective, repeated measures group design n = 12	Adults; not specified	Not specified	Not specified
Hamzavi, Pok, Gstoettner, and Baumgarat (2004)	Retrospective case studies n = 7	Age: 38–79; Mean = 58.7	1–4 years	Postlingual
Morera, Manrique, Ramos, Garcia-Ibanez, and Cavalle et al (2005)	Prospective, repeated measures group design n = 12	Age: 23–75; Mean = 46.17	6 months	Postlingual
Dunn, Tyler, and Witt (2005)	Prospective, cross-sectional n = 12	Age: 48–83; Mean = 64	3 months to 10 years	Postlingual
Ching, Incerti, and Hill (2004)	Prospective, repeated measures group design n = 21	Age: 25–78; Mean = 61.9	1.0–8.8 years	Postlingual
Luntz, Shpak, and Weiss (2005)	Prospective, repeated measures group design n = 12	Age: 7–60; Mean = 25.2	1–6 months and 6–12 months	3 prelingual, 9 postlingual
Ching, van Wonrooy, Hill, and Dillon (2005)	Prospective, groups × 3, repeated measures n = 38 (15 NH, 23 HI)	Age: 6.5–78; Mean (for all Ss) = 30.3; Mean (adult only) = 56.5	1.7–4.8 years	Prelingual and postlingual
Mok, Grayden, Dowell, and Lawrence (2006)	Prospective, repeated measures group n = 14	Age: 37–83; Mean = 53.6	HA experience at least 3 years before CI	3 prelingual, 11 postlingual

Note: Research designs, population characteristics, and results are summarized. Ratings for level, grade, and strength of evidence are also provided. *Evaluation score determined by MacDermid (2004); Ss = Subjects.

aid listeners utilize both interaural timing and binaural redundancy cues, bimodal users only rely on the latter. They theorized that the hearing aid and implant provide different time delay cues and that this likely contributes to variable results obtained in localization skills.

Outcome Measurements

Outcome measurements varied across the 11 studies but provide information reflecting client functioning across different domains. All of the studies used a sentence recognition task that was either performed in

Table 2. Extended

PTA dB HL (500, 1000, and 2000 Hz) (nonimplanted ear)	Level	Grade	Strength	Score*	Results
Mean PTA 97 dB	5	D	III	17	Improved speech intelligibility better than expected from CI + HA alone. No change in thresholds for warble tones.
Mean PTA 86 dB 500 Hz (70–85) 1 kHz (75–95) 2 kHz (85–115)	5	D	II	17	Binaural advantage for CI + HA in noise for 2/3 Ss when noise at CI side. Ability to localize improved in 2/3 Ss, but all reported preferring the CI + HA condition.
Measurable hearing in 250–2000 Hz range	5	D	III	13	Improved speech perception in noise when noise at CI and HA in opposite ear.
Mean PTA 107 dB Range: 75–112 dB	4	C	II	25	Largest benefit reported for speech scores in noise in CI + HA condition. Statistical significance only observed for American listeners.
Mean PTA 101 dB 500 Hz (75–120) 1 kHz (85–120) 2 kHz (80–120)	4	C	II	22	Number recognition with CI alone was 79% and 88% in the CI + HA condition. Monosyllable recognition with CI alone was 37% and improved to 42% with the CI + HA condition. Sentences scores improved from 83% in the CI alone condition to 98% in the CI + HA condition.
Mean PTA 87 dB 500 Hz (45–110) 1 kHz (85–110) 2 kHz (50–120)	4	C	II	28	Significant improvement in word recognition in quiet in the CI + HA (94%) vs. CI alone (62.8%). Improved word understanding in noise from <30% (pre-op) to 64% (post-op) when noise at CI side.
Not specified	4	B	II	30	Significant improvement for 83% of Ss on CNC in the CI + HA condition. Significant improvement on CUNY sentence scores. Localization task showed wide variability in performance.
Mean PTA 107 dB Range: 500 Hz (65–125) 1 kHz (75–125) 2 kHz (85–125)	3	B	II	31	Speech tests were significantly improved in CI + HA. Fewer errors on localization task. Functional performance was significantly higher for 48% of the subjects in the CI + HA condition.
Mean PTA 96 dB Range: 83–120 dB	3	B	II	28	No significant differences in sentence scores at 6 mos. post-op in CI + HA (41.4%) vs. CI alone (34.9%). Significant improvement at 12 mos. post-op in the CI + HA (75.5%) vs. CI alone (60.6%). No significant differences in localization tasks between 6 mos. and 12 mos. post-op.
Mean PTA 106 dB 500 Hz (65–115) 1 kHz (80–115) 2 kHz (80–125)	3	B	II	36	Adults showed significant improvement in the CI + HA condition on BKB sentence test in noise. Children did not show improvement in the CI + HA condition. Normal hearing and binaural HA Ss used interaural timing cues to improve sentence recognition in noise, but Ss in the CI + HA condition did not use interaural timing cues.
Mean PTA not specified, <90 dB HL in the low frequencies in the nonimplanted ear	3	B	II	30	6 adults showed significant improvement on CUNY and 5 showed significant improvement on closed set spondees. Results suggested participants with poorer aided thresholds in mid-high frequencies showed greater bimodal benefit

quiet only (Waltzman et al, 1992; Hamzavi et al, 2004), noise only (Ching et al, 2004; Ching et al, 2005; Dunn et al, 2005; Luntz et al, 2005; Mok et al, 2006), or in both quiet and noise (Tyler et al, 2002; Kileny et al, 2004; Morera et al, 2005). Seven of these studies used monosyllabic word recognition in quiet and/or noise (Waltzman et al, 1992; Armstrong et al, 1997; Tyler et al, 2002; Hamzavi et al, 2004; Dunn et al, 2005; Morera et al, 2005; Mok et al, 2006).Three studies used conventional warble tone measurements (Waltzman et al, 1992; Hamzavi et al, 2004; Morera et al, 2005). Four recent studies used localization tasks among their outcome measures (Tyler et al, 2002; Ching et al, 2004; Kileny et al, 2004; Dunn et al, 2005). Although several studies did include cursory comments from participants, only two studies used questionnaires to

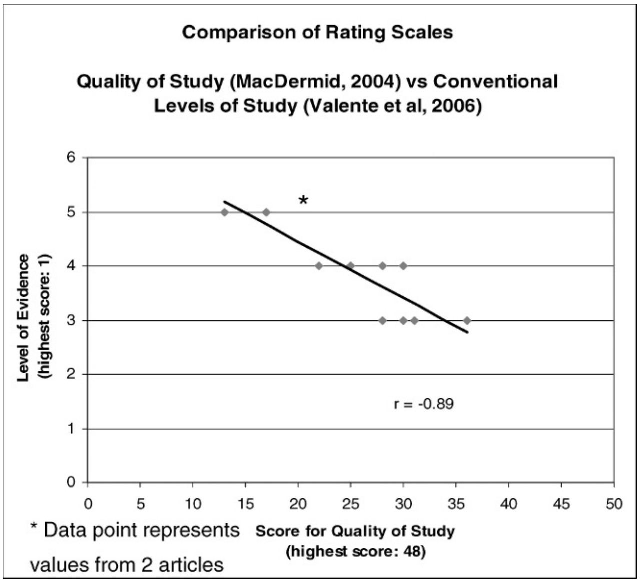

Figure 1. Mean score among the studies was 25 (SD = 7.11). Results showing a strong negative correlation (r = −.89) between conventional levels of evidence (Valente et al, 2006) and quality of study using the MacDermid (2004) scale score.

document self-report results about functional abilities (Tyler et al, 2002; Ching et al, 2004). Questionnaires were generated by researchers in both studies. Ching and colleagues (2004) designed a quantitative questionnaire that included questions based on three subscales: (1) the overall use of hearing aid with the implant; (2) communication function in quiet settings; and (3) communication function in noisy settings. Participants answered questions using a 0–4 point rating scale. In contrast, Tyler and colleagues (2002) used a qualitative scale that posed questions about how sound was integrated between the implant and the hearing aid and why participants chose to use hearing aids with their implants.

DISCUSSION AND CONCLUSION

Trends in Bimodal Stimulation

Since there were a variety of study designs, populations, and outcome measurements used to evaluate the effectiveness of bimodal stimulation, clear and overarching conclusions are difficult to make. However, several trends were observed which include: (1) significantly better speech understanding in the bimodal condition for many participants; (2) largest bimodal benefits in speech recognition were observed in noise; (3) variable findings on localization tasks; and (4) overall significant improvement in functional ability based on self-assessments.

The majority of experiments illustrate that participants performed better in the CI + HA (cochlear implant with hearing aid) condition compared to the CI or HA alone conditions (Armstrong et al, 1997; Tyler et al, 2002; Ching et al, 2004; Hamzavi et al, 2004; Ching et al, 2005; Dunn et al, 2005; Luntz et al, 2005; Morera et al, 2005). The magnitude of improvement in the CI + HA condition may be similar to a "super added" effect where the amount of improvement in an auditory plus visual condition was more than the sum of either auditory or visual alone (Massaro and Cohen, 1999). In addition, these studies suggested that individuals with more residual hearing demonstrated better performance than those with less residual hearing. Three groups of researchers found that the amount of binaural benefit observed in bimodal fittings is correlated with the amount of residual hearing in the nonimplanted ear (Waltzman et al, 1992; Tyler et al, 2002; Hamzavi et al, 2004) suggesting that the poorer-hearing ear should be considered for implantation, leaving the better-hearing ear for hearing aid use (Francis et al, 2005). These outcomes are consistent with widely published literature (Cohen et al, 1993; Clark, 2003) showing the postoperative benefits of monaural implants over hearing aids. Although Ching et al (2004) reported no correlation with degree of hearing loss (for the low frequencies) in the nonimplanted ear and bimodal benefit; they used stringent criteria for significance in their statistical analysis.

A few subjects actually performed worse in the CI + HA condition (Dunn et al, 2005; Luntz et al, 2005). In the Dunn investigation (2005) participants who performed worse in noise on the sentence task were evaluated only at six months postoperative. Reevaluation at a later date postoperative may have shown improvement in recognition as demonstrated by Luntz and colleagues (2005). This finding suggests that plasticity of the auditory system may be affecting the rate at which individuals are able to integrate acoustic and electric stimulation. Plasticity is the capacity of the nervous system to reorganize itself (Bavelier and Neville, 2002). Like other sensory systems, the central auditory nervous system (CANS) has demonstrated the ability to reorganize across the lifespan. In-depth reviews are available that highlight the extent of plasticity observed in the auditory system (Palmer et al, 1998; Syka, 2002). In light of this body of research, it seems reasonable that speech recognition may be worse after initial bimodal fittings in comparison to performance after extensive use. Patients may need encouragement beyond six months to continue using amplification with their implant until adequate reorganization in the central auditory nervous system occurs. In the experiment by Luntz and colleagues (2005), several participants achieved improved speech recognition in noise after extensive (7–12 months) CI + HA use. However, five participants did not show this same benefit, suggesting that some individuals may actually experience binaural interference. Binaural interference has been identified among some binaural hearing aid users (Walden and Walden, 2005) and could also account for the poorer performance among some individuals using bimodal stimulation. One method to evaluate for binaural interference includes measuring speech recognition in noise where speech and noise are presented in front of the listener in both the CI alone and CI + HA conditions (Ching, 2005).

Although some improvement was reported in the CI + HA for word and sentence recognition in quiet, the most significant improvements were observed in noise (Hamzavi et al, 2004; Ching et al, 2005; Dunn et al, 2005; Luntz et al, 2005; Morera et al, 2005) in both new and experienced users (Ching et al, 2004). These results are consistent with benefits widely observed with binaural amplification (Mueller and Hall, 1998) where the auditory system demonstrates the ability to suppress noise when information is available to two ears rather than one. Two of these studies demonstrated that participants obtained better speech understanding when the noise was on the side of implant rather than on the HA side (Tyler et al, 2002; Kileny et al, 2004), highlighting additional benefits of electric and acoustic processing of speech in noise. This finding may not be surprising to clinicians but may not be initially evident to bimodal users. Reminding clients to position themselves with their implant towards the noise source could provide an additional strategy that can be used to enhance understanding in noise.

Findings on localization ability with bimodal stimulation are mixed. Poor localization ability was reported by Kileny et al (2004) from both participants, even though speech recognition was improved in noise. Dunn et al (2005) reported that participants demonstrated a wide range in the number of localization errors in the CI + HA condition. These measurements were made three months postoperative, which may have not been adequate time for the brain to integrate both of these signals and reorganization of the CANS to occur. Other studies suggested that fewer errors were observed in the CI + HA condition during localization tasks (Tyler et al, 2002; Ching et al, 2004; Kileny et al, 2004; Dunn et al, 2005). Two of the three participants evaluated by Tyler et al (2002) demonstrated improved ability to localize in the bimodal condition. Ching et al (2004) found that participants who made fewer localization errors also demonstrated better binaural speech perception. These mixed findings are not surprising when interpreted in light of the difficulty that implant users face in maximizing localization cues. Although able to utilize binaural redundancy cues, implant users are unable to capitalize on ITD cues as described by Ching and colleagues (2005).

Participants in two studies reported improvement in overall functional performance when using bimodal amplification (Tyler et al, 2002; Ching et al, 2004). The results from the functional performance assessment designed by Ching and colleagues (2004) showed that participants reported using the CI + HA over 80% of the time. Participants rated perception of their communication function higher in the CI + HA condition compared to the CI alone. All participants scored significantly better in at least one of the subtests: communication function in quiet, communication function in noise, or awareness of environmental sounds. Variable themes emerged from the qualitative questionnaire used in the study by Tyler et al (2002) illustrating the challenges that some recipients encounter when trying to integrate bimodal stimulation. Two participants reported that although sound was perceived in both ears, a single image emerged (binaural fusion). In contrast, an additional subject reported that sound was louder on the implant side and was always heard as two separate images, which is consistent with findings reported by Blamey et al (2000). Despite individual differences for some questions, all three participants reported preferring using bimodal stimulation compared to monaural electric stimulation alone. Although functional performance appeared to improve among participants in both of these studies, it is unclear how valid these findings are since the questionnaires used were produced for research purposes and were not standardized or validated. Use of standardized assessments could have improved the validity of these findings.

Challenges for Audiological Clinical Research

Initial impressions of the distribution of evidence may lead some individuals to conclude that the audiological research base is not represented by high quality evidence. However, since EBP was developed in medicine, much of its seminal work was conducted in drug therapy where random control trials and use of placebo treatment protocols are common practice. Protocol that includes blinding of patients and evaluators about treatments is also common. In contrast, most audiological research is conducted in clinical populations, which make random assignment to treatment groups as well as blinding of evaluators and patients very difficult. Although some audiological studies have been conducted using random control trials (Mulrow et al, 1992; Yueh et al, 2001), it seems unlikely that most audiological research will produce the highest levels of evidence for intervention studies because of the constraints imposed by a clinical environment. Additionally, small sample sizes are common in audiological research in part because of low incidence of hearing related disorders. In this search, sample sizes ranged from 2 to 38 participants, illustrating the low incidence of bimodal users who were available and willing to participate. A disadvantage of small sample sizes is with respect to interpreting the results. With such experimental designs, researchers cannot be certain that a measured difference is attributable to the intervention or if there are too few participants in the study to detect a statistically significant difference between groups. Such research challenges can be addressed by performing a power analysis and a sample size calculation in the proper design of experiments (Cox, 2005). A power analysis should be conducted prior to an experiment so that researchers know how many participants are ideal for their experiment. A conventionally agreed upon power level of .8 (Huck and Cormier, 1996) is frequently cited so that reasonable differences from the null hypothesis can be detected. No studies in this review reported using an a priori or post hoc power analysis or sample size calculation. Although not ideal, the lack of traditionally viewed high quality evidence in audiology is a reality for some clinical questions at this time. This does not mean that the existing research is poor but, rather, that it may not be effective for all patients. At this point audiologists must exercise clinical judgment to consider how these individual differences might affect outcomes for their patients.

Conclusion

The preponderance of evidence from this review received grades of B or C and yielded a final rating of II indicating "moderate" strength for the recommendation of using amplification in conjunction with implantation for adults. Although evidence supporting this recommendation does not qualify as "strong," it appears to be of adequate strength for audiologists to encourage implant recipients to use bimodal stimulation. For individuals contemplating bilateral implantation, a bimodal fitting may be a reasonable treatment option to implement prior to proceeding to a second surgical procedure.

Although overall conclusions can be drawn from this systematic review, knowledge gaps in the findings remain. For example, we do not know when implant users should actually start using amplification. Should hearing aid use begin immediately in conjunction with the implant fitting, or should amplification be postponed one month, three months, or six months? Clearly the hearing aid settings are also integral to the success of a bimodal fitting. Ching et al (2004) suggests that an NAL-NL1 fitting algorithm be used for initial bimodal fittings and adjusted thereafter. An alternative approach is to use an adaptive dynamic range optimization (ADRO) signal processing hearing instrument that matches the ADRO processing features of some implant systems (Blamey, 2005). However, it is not clear which hearing aid fitting yields the best outcomes or if some individuals perform better with one strategy or another. Identifying a profile of candidates who would optimally benefit from using amplification would be clinically useful for audiologists providing these services. Preliminary results from Morera and colleagues (2005) suggested that individuals who demonstrate speech discrimination ability greater than 20% preoperative present with better outcomes with bimodal stimulation; however, additional research is needed to confirm these findings and determine the best hearing aid settings. The effect of auditory training for individuals using bimodal stimulation also needs to be explored to determine how this affects performance over time. In addition, continued research is needed to determine the how much auditory training is needed to facilitate this learning process.

A systematic review of the literature may be initially overwhelming to clinicians who are unfamiliar with the process. However, by using critical review sheets, and with practice, this task becomes less daunting. It is likely that the next generation of audiologists will routinely use skills associated with EBP to enhance clinical decision making as they encounter these concepts in coursework while students. As a profession, we are obligated to share these systematic reviews with colleagues and patients facing similar clinical questions. By doing so, we enhance our clinical practice by reducing uncertainty in our decision-making process. In addition our patients will receive higher quality care because they are more fully informed, which is paramount to all consumers of health-care services today.

REFERENCES

Abrams H, McArdle R, Hnath-Chisolm T. (2005) From outcomes to evidence: establishing best practices for audiologists. *Semin Hear* 26:157–169.

American Speech-Language-Hearing Association. (2004) *Evidence-Based Practice in Communication Disorders: An Introduction*. Technical Report. http://www.asha.org/members/deskref-journals/deskref/default.

Armstrong M, Pegg P, James C, Blamey P. (1997) Speech perception in noise with implant and hearing aid. *Am J Otol* 18:S140–141.

Bavelier D, Neville H. (2002) Cross modal plasticity: where and how? *Nat Rev Neurosci* 3:443–452.

Blamey P. (2005) Sound processing in hearing aids and CIs is gradually converging. *Hear J* 58:44–52.

Blamey PJ, Dooley GJ, James CJ, Parisi ES. (2000) Monaural and binaural loudness measures in cochlear implant users with contralateral residual hearing. *Ear Hear* 21:6–17.

Boothroyd A. (2006) Characteristics of listening environments: benefits of binaural hearing and implications for bilateral management. *Int J Audiol* 45, Suppl. 1:S12–19.

Bronkhorst AW, Plomp R. (1988) The effect of head-induced interaural time and level differences on speech intelligibility in noise. *J Acoust Soc Am* 83:1508–1516.

Carhart R. (1965) Monaural and binaural discrimination against competing sentences. *Int J Audiol* 4:5–10.

Castro A, Lassaletta L, Bastarrica M, Alfonso C, Prim MP, de Sarria MJ, Gavilan J. (2005) Quality of life in cochlear implanted patients. *Acta Otorrinolaringol Esp* 56:192–197.

Ching TY. (2005) The evidence calls for making binaural -bimodal fittings routine. *Hear J* 58:32–41.

Ching TY, Incerti P, Hill M. (2004) Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. *Ear Hear* 25:9–21.

Ching TY, van Wanrooy E, Hill M, Dillon H. (2005) Binaural redundancy and inter-aural time difference cues for patients wearing a cochlear implant and a hearing aid in opposite ears. *Int J Audiol* 44:513–521.

Chisolm TH, Johnson CE, Danhauer JL, Portz LJ, Abrams HB, Lesner S, McCarthy PA, Newman CW. (2007) A systematic review of health-related quality of life and hearing aids: final report of the American Academy of Audiology Task Force on the Health-Related Quality of Life Benefits of Amplification in Adults. *J Am Acad Audiol* 18:151–183.

Clark GM. (2003) *Cochlear Implants: Fundamentals and Applications*. New York: Springer.

Cohen NL, Waltzman SB, Fisher SG. (1993) A prospective, randomized study of cochlear implants. The Department of Veterans Affairs Cochlear Implant Study Group. *N Engl J Med* 328:233–237.

Cowan R, Chin-Lenn J. (2004) Pattern and prevalence of hearing aid use post-implantation in adult cochlear implant users. *Aust N Z J Audiol* Suppl. (May):48.

Cox RM. (2005) Evidence-based practice in provision of amplification. *J Am Acad Audiol* 16:419–438.

Cullen RD, Higgins C, Buss E, Clark M, Pillsbury HC, Buchman CA. (2004) Cochlear implantation in patients with substantial residual hearing. *Laryngoscope* 114:2218–2223.

deJong R. (1994) Selecting and verifying hearing aid fittings for symmetrical hearing loss. In: Valente M, ed. *Strategies for Selecting and Verifying Hearing Aid Fittings*. New York: Thieme, 180–206.

Dunn CC, Tyler RS, Witt SA. (2005) Benefit of wearing a hearing aid on the unimplanted ear in adult users of a cochlear implant. *J Speech Lang Hear Res* 48:668–680.

Festen JM, Plomp R. (1986) Speech-reception threshold in noise with one and two hearing aids. *J Acoust Soc Am* 79:465–471.

Francis HW, Yeagle JD, Bowditch S, Niparko JK. (2005) Cochlear implant outcome is not influenced by the choice of ear. *Ear Hear* 26, Suppl. 4:7S–16S.

Gantz BJ, Turner CW. (2003) Combining acoustic and electrical hearing. *Laryngoscope* 113:1726–1730.

Gelfand S. (1997) *Essentials of Audiology*. New York: Thieme.

Gelfand SA, Silman S, Ross L. (1987) Long-term effects of monaural, binaural and no amplification in subjects with bilateral hearing loss. *Scand Audiol* 16:201–207.

Hamzavi J, Baumgartner WD, Pok SM, Franz P, Gstoettner W. (2003) Variables affecting speech perception in postlingually deaf adults following cochlear implantation. *Acta Otolaryngol* 123: 493–498.

Hamzavi J, Pok SM, Gstoettner W, Baumgartner WD. (2004) Speech perception with a cochlear implant used in conjunction with a hearing aid in the opposite ear. *Int J Audiol* 43: 61–65.

Hawkins DB. (2005) Effectiveness of counseling-based adult group aural rehabilitation programs: a systematic review of the evidence. *J Am Acad Audiol* 16:485–493.

Hirsh IJ. (1950) Binaural hearing aids: a review of some experiments. *J Speech Disord* 15:114–123.

Huck S, Cormier W. (1996) *Reading Statistics and Research*. New York: Harper Collins.

Kileny R, Snorrason R, Zwolan T, Macpherson E, Middlebrooks JC. (2004) Contralateral hearing aid benefit in patients with cochlear implants. *Int Congress Ser* 1273:231–234.

Kong YY, Cruz R, Jones JA, Zeng FG. (2004) Music perception with temporal cues in acoustic and electric hearing. *Ear Hear* 25: 173–185.

Lou J. (2002) Searching for the evidence. In: Law M, ed. *Evidence-Based Rehabilitation*. New Jersey: Slack, 71–94.

Luntz M, Shpak T, Weiss H. (2005) Binaural-bimodal hearing: concomitant use of a unilateral cochlear implant and a contralateral hearing aid. *Acta Otolaryngol* 125:863–869.

MacDermid JC. (2004) An introduction to evidence-based practice for hand therapists. *J Hand Ther* 17:105–117.

Massaro DW, Cohen MM. (1999) Speech perception in perceivers with hearing loss: synergy of multiple modalities. *J Speech Lang Hear Res* 42:21–41.

Miller G, Nicely P. (1955) An analysis of perceptual confusions among some English consonants. *J Acoust Soc Am* 27:338–352.

Mok M, Grayden D, Dowell RC, Lawrence D. (2006) Speech perception for adults who use hearing aids in conjunction with cochlear implants in opposite ears. *J Speech Lang Hear Res* 49: 338–351.

Moore B. (2003) *An Introduction to the Psychology of Hearing*. London: Academic Press.

Morera C, Manrique M, Ramos A, Garcia-Ibanez L, Cavalle L, Huarte A, Castillo C, Estrada E. (2005) Advantages of binaural hearing provided through bimodal stimulation via a cochlear implant and a conventional hearing aid: a 6-month comparative study. *Acta Otolaryngol* 125:596–606.

Mueller HG, Hall JW. (1998) *Audiologist's Desk Reference.* Vol. 2. San Diego: Singular Publishing Group.

Mulrow CD, Tuley MR, Aguilar C. (1992) Sustained benefits of hearing aids. *J Speech Hear Res* 35:1402–1405.

Offeciers E, Morera C, Muller J, Huarte A, Shallop J, Cavalle L. (2005) International consensus on bilateral cochlear implants and bimodal stimulation. *Acta Otolaryngol* 125:918–919.

Palmer CV, Nelson CT, Lindley GA 4th. (1998) The functionally and physiologically plastic adult auditory system. *J Acoust Soc Am* 103:1705–1721.

Qin MK, Oxenham AJ. (2003) Effects of simulated cochlear-implant processing on speech reception in fluctuating maskers. *J Acoust Soc Am* 114:446–454.

Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. (1996) Evidence based medicine: what it is and what it isn't. *Br Med J* 312:71–72.

Silman S, Silverman CA, Emmer MB, Gelfand SA. (1992) Adult-onset auditory deprivation. *J Am Acad Audiol* 3:390–396.

Silverman CA, Silman S, Emmer MB, Schoepflin JR, Lutolf JJ. (2006) Auditory deprivation in adults with asymmetric, sensorineural hearing impairment. *J Am Acad Audiol* 17:747–762.

Sweetow R, Palmer CV. (2005) Efficacy of individual auditory training in adults: a systematic review of the evidence. *J Am Acad Audiol* 16:494–504.

Syka J. (2002) Plastic changes in the central auditory system after hearing loss, restoration of function, and during learning. *Physiol Rev* 82:601–636.

Threats TT. (2006) Towards an international framework for communication disorders: use of the ICF. *J Commun Disord* 39: 251–265.

Tyler RS, Parkinson AJ, Wilson BS, Witt S, Preece JP, Noble W. (2002) Patients utilizing a hearing aid and a cochlear implant: speech perception and localization. *Ear Hear* 23:98–105.

Valente M, Abrams HB, Benson D, Chisolm TH, Citron D, Hampton D. (2006) Guidelines for the audiologic management of adult hearing impairment. *Audiol Today* 18:32–36.

Walden TC, Walden BE. (2005) Unilateral versus bilateral amplification for adults with impaired hearing. *J Am Acad Audiol* 16:574–584.

Waltzman SB, Cohen NL, Shapiro WH. (1992) Sensory aids in conjunction with cochlear implants. *Am J Otol* 13:308–312.

World Health Organization. (2001) *International Classification of Functioning, Disability and Health (ICF)*. Geneva: World Health Organization.

Yueh B, Souza PE, McDowell JA, Collins MP, Loovis CF, Hedrick SC, Ramsey SD, Deyo RA. (2001) Randomized trial of amplification strategies. *Arch Otolaryngol Head Neck Surg* 127:1197–1204.

Appendix 1. MacDermid (2004) Critical Review Sheet

Evaluation of Study Design			
Evaluation Criteria	Score		
Study question	2	1	0
1. Was the relevant background work cited to establish a foundation for the research question?			
Study design			
2. Was a comparison group used?			
3. Was patient status at more than one time point considered?			
4. Was data collection performed prospectively?			
5. Were patients randomized to groups?			
6. Were patients blinded to the extent possible?			
7. Were treatment providers blinded to the extent possible?			
8. Was an independent evaluator used to administer outcome measures?			
Subjects			
9. Did sampling procedures minimize sample/selection biases?			
10. Were inclusion/exclusion criteria defined?			
11. Was an appropriate enrollment obtained?			
12. Was appropriate retention/follow-up obtained?			
Intervention			
13. Was the intervention applied according to established principles?			
14. Were biases due to the treatment provider minimized (i.e., attention, training)?			
15. Was the intervention compared with the appropriate comparator?			
Outcomes			
16. Was an appropriate primary outcome defined?			
17. Were appropriate secondary outcomes considered?			
18. Was an appropriate follow-up period incorporated?			
Analysis			
19. Was an appropriate statistical test(s) performed to indicate differences related to the intervention?			
20. Was it established that the study had significant power to identify treatment effects?			
21. Was the size and significance of the effects reported?			
22. Were missing data accounted for and considered in analyses?			
23. Were clinical and practical significance considered in interpreting results?			
Recommendations			
24. Were the conclusions/clinical recommendations supported by the study objectives, analysis, and results?			
Total Quality Score (Sum of above/48) =			
Level of Evidence (Sackett) 1 ☐ 2 ☐ 3☐ 4☐ 5☐			

Source: Reprinted with permission from MacDermid (2004).