The Use of Mild Gain Hearing Aids for Adults with Auditory Processing Difficulties

Capstone

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By

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Abstract

The purpose of the present study was to investigate the effect of mild gain hearing aids with directional microphones and noise reduction in adults with auditory processing difficulties. Eleven adults with normal peripheral hearing but complaints and case history consistent with auditory processing difficulties completed speech in noise testing with and without the use of hearing aids and completed questionnaires addressing listening difficulties following testing with and without hearing aids. They also answered a question about their perception of anxiety during testing with and without hearing aids. The adults demonstrated significant improvements on speech in noise testing and on the questionnaires regarding listening difficulty. The majority of them also reported less anxiety during testing when wearing the hearing aids. Future research should include a larger sample size, a longer trial of amplification, should investigate different settings for the hearing aids, and should address subject anxiety in a more specific and measurable way.

Dedication

This capstone project is dedicated to my family and to my fiancé, Tim. Without their love, support, and patience this project would have remained an overwhelming idea.

Acknowledgments

I would like to express my gratitude to my committee members, Christina Roup, Ph.D., Gail Whitelaw, Ph.D., and Robert Fox, Ph.D., as well as to Christy Goodman, Au.D., for their support during this project and throughout my time at The Ohio State University. These individuals have each impacted my professional development and personal growth in many ways and I am very grateful for their roles in my graduate career. I would also like to express appreciation to Francis Kuk, Ph.D., for his insights and recommendations for the study design and to Widex for their support of this project and for providing the hearing aids for use in the study.

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Field of Study: Audiology

Table of Contents

List of Figures

List of Abbreviations

AAA	American Academy of Audiology
APD	Auditory Processing Disorder
ASHA	American Speech-Language-Hearing Association
BASC-2	Behavioral Assessment System for Children
CAP	Central Auditory Processing
COOP-A	Dartmouth Primary Care Cooperative Information Project Charts for Adolescents
FM	Frequency Modulation
HHIA	Hearing Handicap Inventory for Adults
R-CHAPPS	Revised Children's Auditory Processing Performance Scale
SNR	Signal to Noise Ratio
SSRS	Social Skills Rating System

Chapter 1

Introduction

Auditory processing disorder (APD) is a diverse disorder characterized by deficits in the processing of information delivered auditorily (American Academy of Audiology [AAA], 2010; American Speech-Language-Hearing Association [ASHA], 2005). APD can be developmental or acquired through trauma or lesion to the brain. Common difficulties experienced by people with APD include listening to a signal in the presence of background noise, listening to a degraded signal, following rapid speech, understanding on the telephone, recognizing the subtle changes in speaker prosody that indicate humor or sarcasm, following directions, and maintaining attention and focus (AAA, 2010). APD affects both children and adults and can result in learning difficulties, auditory fatigue, anxiety, behavioral issues, and psychosocial issues (ASHA, 2005; Kreisman, John, Kreisman, Hall, & Crandell, 2012; Keith & Purdy, 2014).

While difficulties like listening in background noise may seem like a minor inconvenience, individuals with APD are significantly impacted by their inability to process auditory information like their normal hearing (and processing) peers. Individuals with auditory processing difficulties are negatively impacted by their impairments at school, work, and in social settings and may experience anxiety, frustration, and social withdrawal (Bellis, 2002; Keith & Purdy, 2014). APD in children causes academic struggles for if a child cannot focus on a teacher’s voice in a noisy classroom or becomes exhausted during the day due to the increased auditory effort of listening to a degraded signal through a degraded auditory system then that child cannot learn effectively. Children with APD are sometimes misdiagnosed as having attention or behavioral problems. Some children with APD develop behavioral problems as a result of their frustration at their own inability to learn as easily as their peers.

Adults with APD encounter similar frustrations and barriers to success due to their disorder. Adults with APD may experience difficulty maintaining focus in complex listening environments like is expected at workplace meetings. They may be unable to function well in jobs due to auditory fatigue or be mislabeled as unable to perform and multitask because they have difficulty following multistep directions delivered auditorily (Rosenberg, 2002; McCreery, Venediktov, Coleman, & Leech, 2012). These individuals may withdraw or even avoid social interactions entirely because of their frustration and anxiety surrounding communicating in noisy situations (Keith & Purdy, 2014; Kreisman et al., 2012.) There are likely many adults with APD that are not identified as it was not common to test for APD until the last few decades. Parents of children with APD frequently report similar difficulties as those experienced by their child. Additionally, some individuals acquire APD through traumatic brain injury although their difficulties may not be identified immediately (Gallun, et al., 2012).

Management strategies and treatments include the implementation of environmental modifications such as preferential seating, increasing access to the desired signal through the use of a sound field or personal FM system or through mild gain hearing aids, auditory training programs, and supplementation of auditory materials with visual aids (Kuk, Jackson, Keenan, & Lau, 2008; Kuk, 2011). As individuals with APD are often considered to have normal hearing because their pure tone audiogram does not reflect their difficulties, hearing aids are a frequently overlooked treatment option for this population (Keith & Purdy, 2014).

A study by Kuk and colleagues in 2008 examined the benefit of fitting children diagnosed with APD with mild gain hearing aids. Kuk and colleagues found that the children's performance on tests of speech perception in noise improved when wearing mild gain hearing aids equipped with noise management and directional microphones, although the results did not reach statistical significance. Additionally, the researchers reported the children also showed improvement on subjective measures of listening difficulty following hearing aid fitting (Kuk et al., 2008). To the investigator's knowledge no such study has been done in an adult population.

The goal of the current project was to investigate the use of mild gain hearing aids equipped with noise management and directional microphones in a group of adults with normal peripheral hearing and difficulty processing auditory information. In order to obtain a larger sample of subjects for this study, adults with complaints common to individuals with APD were recruited. A diagnosis of APD was not a requirement for participation for the following reasons: only including individuals with a prior diagnosis of APD would have greatly reduced the number of eligible participants, restricting participation to adults previously diagnosed with APD would have denied participation to many individuals with symptoms that were likely to be addressed by the treatment, and the literature shows no consensus regarding which test batteries and diagnostic criteria should be used for APD. As a result of these discrepancies, even if individuals had presented for the study with a prior diagnosis of APD we still would have needed to base their inclusion off of their reported symptoms or on their performance on an additional test battery.

The specific aims of this project were:

1. To determine if the use of mild gain hearing aids programmed facilitated a measurable improvement in objective measures of speech in noise for adults with normal hearing and auditory processing concerns.

2. To determine if the use of mild gain hearing aids results in a perceived improvement in speech in noise for adults with normal hearing and auditory processing concerns.

3. To determine if the use of mild gain hearing aids results in a perceived decrease in anxiety during speech in noise testing for adults with normal hearing and auditory processing concerns.

Chapter 2

Literature Review

Defining and diagnosing the disorder:

APD occurs in children and adults and can present with a wide range of auditory symptoms affecting functional performance in several domains including academic, occupational, behavioral, and social (AAA, 2010; ASHA, 2005). Fatigue and anxiety are also a contributing factor to academic, occupational, and social function for individuals with APD. Listening in difficult environments, especially for extended periods of time (like those required for academic or occupational purposes) can cause increased auditory fatigue. Auditory fatigue makes learning new information difficult which can cause problems both in academic and occupational environments as well as in the social domain (Rosenberg, 2002; McCreery et al., 2012). Anxiety in difficult listening situations can cause social withdrawal and isolation resulting in poorer psychosocial status (Keith & Purdy, 2014; Kreisman, John, Kreisman, Hall, & Crandell, 2012). APD is clearly a significant impairment for both children and adults as it may impact learning, psychosocial status, and work performance and satisfaction.

Definitions for APD and criteria for diagnosis are debated in the literature and there is no clear consensus on what evaluation tools and criteria should be employed for diagnosis (Wilson & Arnott, 2013; ASHA, 2005; AAA, 2010; British Society of Audiology, [BSA], 2011; Moore, 2011). Some researchers argue for diagnostic tests that rely on nonspeech stimuli only to avoid misdiagnosing a language disorder as APD (Dawes &

Bishop, 2009; McArthur, 2009), whereas others suggest use of test materials that use both speech and nonspeech stimuli (BSA, 2011). In addition, others recommend using behavioral questionnaires which will expose subjects' experiences and difficulties in real-world environments (Ferguson, Hall, Riley, & Moore, 2011).

In addition to the lack of consensus on test materials there is debate over what qualifies as disordered. ASHA (2005) recommends that performance must be at least two standard deviations below the mean on two or more tests used in the test battery, but does not specify whether performance must be deficient in one or both ears. AAA (2010) recommends that performance be at least two standard deviations below the mean for at least one ear on at least two behavioral central auditory tests. The Bellis-Ferre model (1999) as well as the Buffalo Model [Florida Department of Education (2001)] recommend that the pattern of auditory processing test results also be considered in diagnosing APD in order to classify specific subprofiles of APD to aid in identifying the area (or areas) of dysfunction and to guide intervention strategies.

Wilson and Arnott (2013) conducted a retrospective study in which they examined the test results for 150 children aged 7.0-15.6 years who had presented for a central auditory processing evaluation. This study examined many commonly used diagnostic criterions for APD and highlights the inconsistencies in rate of diagnosis. They classified each child as potentially having APD or not having APD using 9 different diagnostic criteria seen in the literature and found potential diagnosis rates ranging from 7.3%-96.0% for the different criteria. Such a large range demonstrates that the specific criteria used to arrive at a diagnosis of APD could result in great differences in presentation and severity of symptoms and APD test results for different individuals with the same diagnosis of APD. This causes confusion in researching this area because comparing between studies, treatments, and results is difficult when the population of interest is so variable. While Wilson and Arnott (2013) did not suggest that one set of diagnostic criteria is preferred over the others, they recommended that clinicians and researchers clearly state which tests and diagnostic criteria were used for a study.

Clearly there is currently no consensus on test materials or diagnostic criterion for APD, however recent interest in the areas of APDs and learning disabilities has resulted in an increase in children and young adults who present to audiologists for auditory processing evaluations.

Heine and Slone (2008) reported that referrals for auditory processing testing have increased as the visibility of the disorder has grown. Heine and Slone (2008) also pointed out that although the correlation between APD and other learning difficulties is recognized, there has not been significant exploration of APD as a potential cause of learning difficulties in adolescents. In their 2008 study, Heine and Slone investigated the effects of mild APD in three adolescents who were referred for APD testing after exhibiting unexplained academic difficulties and classroom behaviors such as distractibility, difficulty following directions, and trouble listening in noise. The participants were evaluated for APD and found to have deficits in the areas of auditory closure, auditory figure-ground, and dichotic listening as well as some short term auditory memory deficits. Each of the adolescents participated in four individual therapy sessions which addressed their areas of deficit and were provided with activities and strategies for use at home to improve their auditory skills. Follow-up testing and reports from parents and school staff showed improvement in deficit areas for all three adolescents as well as improved academic performance and increased confidence. Heine and Slone (2008) suggest that mild auditory processing deficits previously thought not to be significant enough to merit intervention may become significant for adolescents as school demands increase while they are simultaneously undergoing increased physiological, psychological, and emotional challenges and changes associated with adolescence.

While academic struggles are certainly critical and require addressing, an additional key area of concern is the psychosocial domain. While there has been limited investigation into APD and psychosocial status, negative associations between hearing loss and psychosocial status have been demonstrated in both children and adults (Davis, Elfenbein, Schum, & Bentler 1986; Bess, Dodd-Murphy, & Parker, 1998; Arlinger, 2003; Nachtegaal et al., 2009). Kreisman and colleagues explored the impact of APDs on psychosocial status in a 2012 study using a two-matched group design. The APD group consisted of 19 children between 9.5 and 17.8 years old who had received a diagnosis of APD and the control group consisted of 20 children (matched for age and gender to the APD group). The children and their mothers completed the following questionnaires that address the psychosocial domain: the Dartmouth Primary Care Cooperative Information Project Charts for Adolescents (COOP-A), the Behavioral Assessment System for Children (BASC-2), and the Social Skills Rating System (SSRS). The researchers found that some subscales of the COOP-A, BASC-2, and SSRS revealed significantly greater psychosocial difficulty for children in the APD group. Kreisman and colleagues concluded that children with APD are at significantly greater risk for psychosocial difficulties.

Keith and Purdy (2014) report that children with APD experience frustration and anxiety around learning because of the additional effort required for them (Keith & Purdy, 2014). These emotions can result in social isolation and low self-esteem. The authors also report that parents of children with APD find that their children are very fatigued after school, a factor which can also influence social withdrawal.

In summary, APD is a diverse disorder affecting many life domains. Diagnosis of APD depends on case history report, observations of the audiologist, standard audiometric evaluation to establish normal peripheral hearing, and demonstrated abnormality on a test battery that assesses auditory processing ability and provides normative data for comparison (AAA, 2010). Test categories that should be included are those that assess dichotic listening, monaural low-redundancy speech perception, localization and lateralization, and auditory discrimination. While some individuals may not receive a diagnosis of APD (due to peripheral hearing loss or scores on the chosen APD battery that do not meet the diagnostic criteria for disordered) they may still experience noticeable and significant auditory processing difficulties which impact many life domains (Baran, 2002; Bellis, 2003; Rodriguez, DiSarno, & Hardiman, 1990; Rosenberg, 2002).

Treating the disorder:

It is established that APD can result in learning difficulties, behavioral issues, and social issues (ASHA, 2005). Treatment strategies may involve one or more of several areas: modifying the listening environment, teaching compensatory strategies, or engaging in direct therapy (Rosenberg, 2002). Treatments employed for children with APD include the implementation of various classroom modification strategies such as preferential seating, the use of a sound field or personal FM system, supplementation of auditory materials with visual aids, and mild gain hearing aids (Kuk et al., 2008; Kuk, 2011). Adults with APD experience similar symptoms and difficulties as do children, however, their daily communication environments are often outside of classrooms or lecture halls and may be less conveniently treatable through environmental modifications. Treatments for APD in adults include aural rehabilitation, use of a personal FM system, auditory training programs, and hearing aids (Jerger, Chmiel, Florin, Pirozzolo, & Wilson, 1996; Crandell & Smaldino, 2001; Crandell, Horn, Lewis, & Valente, 2004; Boothroyd, 2004; McArdle, Abrams, & Chisolm, 2005; Johnson, John, Kreisman, Hall, & Crandell, 2009; Chmiel & Jerger, 1996; Kricos, 2006; Keith & Purdy, 2014).

Evidence for treatments which improve the signal to noise ratio (SNR):

Many studies have reported that fitting individuals with APD with an FM system results in improvements in speech perception in noise (Jerger, Chmiel, Florin, Pirozzolo, & Wilson, 1996; Crandell & Smaldino, 2001; Crandell, Horn, Lewis, & Valente, 2004; Boothroyd, 2004; McArdle, Abrams, & Chisolm, 2005; Johnson, John, Kreisman, Hall, & Crandell, 2009; Keith & Purdy, 2014). The improvement in performance is attributed to the improved SNR provided by an FM system (Keith & Purdy, 2014). Improving the SNR for the individual allows them greater access to the information in the speech signal without the negative effects of reverberation, distance, and interfering noise. Personal FM systems are the most effective way to improve the SNR and have been shown to improve speech recognition in the presence of background noise for both hearing impaired and normal hearing listeners (Chisolm, Noe, McArdle, & Abrams, 2007; Jerger et al., 1996; Thibodeau, 2010). These systems are routinely reported to provide a SNR of 10-25 dB (Crandell et al., 2004; Crandell & Smaldino, 2001; Boothroyd, 2004; Chisolm et al., 2007).

Individuals with APD can also benefit from the improved SNR provided by this technology. Keith and Purdy (2014) reported on the many benefits of personal FM technology for children with APD including immediate as well as longer term therapeutic effects of amplification (Keith, W.J., & Purdy, S.C., 2014). Observed benefits include improved hearing and listening in school and at home, improved psychosocial status, and long term neuroplastic changes resulting in better hearing even without the hearing aids suggesting that long term amplification may not be needed. Most children with APD may benefit from personal FM use, however, there are no good predictors of benefit so all children with auditory processing complaints should be given the opportunity to trial a personal FM system. Keith and Purdy (2014) also discuss the use of other forms of amplification such as mild gain hearing aids and soundfield FM systems. They conclude that soundfield FM systems provide at best approximately half the benefit (in terms of improving the SNR) of that of a personal FM system. They also discuss that there is little evidence for mild gain hearing aids as a treatment and note that the possible benefit derived in SNR improvement is slight compared to that of the personal FM system. Keith and Purdy (2014), do note, however, that in situations where the speaker cannot wear the remote microphone portion of their system it can be placed on the listener and achieve a similar effect to that of wearing conventional hearing aids.

Several studies examining personal FM system use found that subjects were not interested in obtaining an FM system following the study despite experiencing significant benefit from the use of one during the study. Some of the main reasons subjects reported for not wishing to obtain an FM system included difficulty of use, inconvenience of use for the patient and the communication partner, and cosmetic issues such as size and appearance of the device (Boothroyd, 2004; Jerger et al, 1996; McArdle et al., 2005). Personal FM systems have become smaller in the past several years and ear level FM systems are similar in size to small behind-the-ear hearing aids. Despite the smaller size and improved cosmetics of newer personal FM technology, FM systems still require the participation of the speaker in wearing a microphone.

Hearing aids are an effective form of aural rehabilitation for adults with hearing loss. Appropriately fit hearing aids can alleviate many of the speech processing difficulties experienced by adults with hearing loss by providing the person with access to much of the auditory information that was being missed because of the hearing loss (Chmiel & Jerger, 1996; Kricos, 2006). Kuk and colleagues (2008; 2011) point out that hearing aids, like FM systems, also provide SNR improvement. Additionally they posit that because the current digital hearing aid technology is smaller than in past generations and more cosmetically appealing then there may be increased acceptance for the wearer and better compliance with use than is seen with personal FM system use. A study by Kuk and colleagues in 2008 examined the benefit of fitting mild gain hearing aids for children with APD. The children wore the hearing aids for six months. Kuk and colleagues (2008) found that the children's performance on the Auditory Continuous Performance Test (in noise) improved when wearing mild gain hearing aids equipped with noise management and directional microphones, although the results did not reach statistical significance. The CHAPPS (Children's Auditory Processing Performance Scale) was administered to the children's parents and teachers at the beginning of the trial and again at the end and while results did not reach statistical significance, improvement was demonstrated on several areas of the CHAPPS.

Directional microphones and noise reduction:

The benefit of using directional microphones in open fit hearing aids has been questioned. Klemp and Dhar (2008) investigated the effect of directional microphones on speech perception in noise for open fit behind-the-ear hearing aids in a group of 16 hearing impaired participants. Aided testing was performed both with the hearing aids in omnidirectional mode and directional mode and those scores were compared to an unaided test condition. Klemp and Dhar (2008) found that performance decreased for the omnidirectional condition when compared to unaided and that performance improved for the directional condition compared to unaided. They report a directional advantage of 2.6 dB over the unaided condition. The authors conclude that directional microphones should be considered when fitting open fit hearing aids.

Magnuassun and colleagues (2013) examined speech recognition in noise performance for 20 hearing impaired new hearing aid users fit with bilateral open fit hearing aids. The participants were tested unaided and aided. The aided testing was performed with the hearing aids in omnidirectional mode, directional mode, and directional mode combined with noise reduction. Magnuassun and colleagues also examined the participants' performance in those same conditions with closed earmolds as a control condition. The omnidirectional condition did not yield a significant improvement in performance when compared to unaided when using either the open fit or closed earmold. There was a significant improvement in performance in speech recognition in noise for the directional microphone condition for both the open fit and closed earmold conditions (1.6 dB for open fit and 4.4 dB for closed earmold). Magnussun and colleagues did not find any further improvement for the open fit configuration when noise reduction was added but did find a significant improvement of 0.8 dB when noise reduction was added for the closed earmold configuration.

McCreery and colleagues (2012) conducted an evidenced-based review investigating the use of digital noise reduction and directional microphones in pediatric hearing aid users. The researchers discuss the improvements in SNR afforded by FM systems (when used in conjunction with hearing aids) in noisy environments, but point out that FM systems are often impractical in situations such as classrooms where group discussions or team projects are occurring. They found four qualifying studies investigating digital noise reduction and seven qualifying studies which addressed directional microphone use in this population. The review concluded the following with a moderate level of evidence: digital noise reduction does not appear to improve nor degrade speech understanding and directional microphones do improve speech understanding. The improvements attributed to directional microphones were in controlled test environments and more research is needed to determine whether this improvement is realized in daily listening environments.

Potential benefit of the current study:

Although APD was described in 1954 (Mykelbust, 1954; Bocca, 1954; ASHA, 2005) understanding and treating developmental APD did not become an area of great interest for several decades. APDs were initially noticed in adult patients with brain lesions and determining site of lesion was the primary focus (Bocca, 1954). It was then several years before an interest developed in APDs which interfered with communication and speech development in individuals without identifiable brain lesions (Katz & Ilmer, 1972). The prevalence of APD has been estimated at 5 to 7% (Chermak & Musiek, 1997; Bamiou, Musiek & Luxon, 2001). Diagnosis of APD is more common in children than in adults however it is also likely that some adults who have a history of difficulty understanding and processing auditory information particularly in difficult listening environments would have been diagnosed with APD if auditory processing testing was common when those adults were children.

FM systems have been shown to be a successful treatment for many individuals with APD (Chisolm, Noe, McArdle, & Abrams, 2007; Jerger et al., 1996; Thibodeau, 2010). The significant improvement in SNR provided by an FM system is credited with the benefit derived however despite perceived benefit, many individuals resist FM systems citing difficulty of use, inconvenience of use for the patient and the communication partner, and cosmetic issues such as size and appearance of the device (Crandell et al., 2004; Crandell & Smaldino, 2001; Boothroyd, 2004; Chisolm et al., 2007; Jerger et al, 1996; McArdle et al., 2005). Hearing aids also provide improvement in SNR (although significantly less than that provided by an FM system) when equipped with directional microphones and noise reduction and have been shown to provide improvement in speech perception in noise in children with APD (Kuk et al, 2008; Magnusson, Laesson, Persson, & Tengstrand, 2013). Keith and Purdy (2014) report that some adults and children with APD do wear conventional (non-remote microphone) hearing aids and benefit according to clinician reports, although there is a lack of evidence in the literature for the treatment.

The primary goal of the current experiment was to provide new information regarding the efficacy of using mild gain hearing aids with directional microphones and noise reduction to improve speech understanding in noise for young adults with auditory processing difficulties. Young adults were chosen as the population of interest as the most often used treatment option, a personal FM system, is not always a good option for this age group. Personal FM system use is often impractical outside of educational settings as it does require the participation of the speaker in wearing the transmitter. Young adults are transitioning out of educational settings and into the work force where their difficulties may become a barrier to their future success. If hearing aids provide measurable and perceivable benefit to adults with auditory processing difficulties than they are likely to be a more acceptable treatment option than personal FM. Additionally, young adults are unlikely to have any age-related hearing loss. While people of all ages may struggle with auditory processing difficulties, recruiting older adults would have likely included those who do have minimal hearing loss. Determining whether the hearing aids were treating the peripheral hearing loss or the central auditory deficits would have been very difficult. Additional goals of this experiment were to determine if wearing the hearing aids during speech in noise testing resulted in a decrease in listening difficulty (as reported through questionnaires) or a decrease in subjects' reports of anxiety during testing. Using hearing aids for adults with auditory processing difficulties is a treatment for which there is little data available and one for which much research is needed. There is significant potential for application of this treatment in young adults with auditory processing difficulties.

Chapter 3

Methods

Research design:

The study was a within-subjects, treatment-effects design investigating the benefit of mild gain hearing aids as a treatment for young adults who exhibit and/or report symptoms consistent with APD. Speech perception in noise was measured with and without the use of mild gain hearing aids programmed with directional microphones and noise reduction. All audiometric and auditory experimental testing was conducted in a sound-attenuating booth. In addition, participants were asked via questionnaires to rate their perceived listening difficulty, hearing handicap, and were asked about their experience of anxiety in the testing environment both with and without the hearing aids.

Subjects:

Eleven adults between the ages of 20 and 40 years (mean = 24.5 years; nine female and two male) participated in the present study. All subjects had normal pure tone thresholds (≤ 20 dB HL 250-8000 Hz) and subjective auditory processing complaints such as difficulty listening in noise, difficulty following rapid talkers, trouble understanding on the telephone, and complaints related to understanding in groups. Additional inclusion criteria included: 1) negative family history of hearing loss; 2) negative history of middle-ear pathology; 3) normal otoscopy; 4) tympanometry within normal limits (Margolis & Hunter, 2000); 5) present ipsilateral and contralateral acoustic reflexes; and

6) bone conduction thresholds within 10 dB of air conduction thresholds at 500-4000 Hz. All subjects were native speakers of English.

The present study was approved by the Behavioral and Social Sciences Institutional Review Board at the Ohio State University. Subjects were recruited via flyers on the Ohio State University campus and through advertisements in electronic media. All testing was completed over two, one to two-hour sessions completed on separate days. Subjects were compensated for their time.

Materials:

The Revised Speech Perception in Noise (R-SPIN) test (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984) was used to measure speech recognition in the present study. The R-SPIN is composed of sets of high and low predictability sentences which are presented in the presence of background noise (i.e., a multitalker babble). The R-SPIN requires the participant to listen to the sentences and background noise and respond verbally by repeating the last word in each sentence. High predictability sentences are ones in which the last word (the target word) of the sentence can be reasonably predicted based on the content of the sentence. Low predictability sentences are ones in which the target word cannot be reasonably predicted based on sentence content. The Hearing Handicap Inventory for Adults (HHIA) (Newman, Weinstein, Jacobson, & Hug, 1990) and revised CHAPPS (Children's Auditory Processing Performance Scale) (Smoski, Brunt, & Tannahill, 1992; Lamoreau, 2011) questionnaires address listening difficulty in different listening situations. The HHIA (Newman, et al., 1990) is designed to assess and quantify the perceived handicap that an individual experiences as a result of hearing loss. There are 25 questions, 12 of which address social impact and 13 of which address emotional impact of hearing loss. The subjects were instructed to ignore the phrase “hearing loss” when it appeared in the instructions and to think about hearing difficulty instead. The CHAPPS questionnaire (Smoski, et al., 1992) is completed by a parent or teacher and assesses a child’s listening difficulty as compared to their peers. There are 36 questions that address many different listening situations. The revised CHAPPS (Lamoreau, 2011) was restructured so that it is more applicable to adults and is completed by the individual.

Procedures:

All subjects completed the SCAN-3A (Keith, 2009) in order to obtain an objective measure of auditory processing ability. The SCAN-3A is a commonly used clinical test battery for the screening of and diagnosing of APD in adults. The SCAN-3A is composed of subtests that examine different auditory skills and processes by requiring the participant to listen to stimuli in several conditions and to repeat back what they heard or to report on what they heard. The four diagnostic subtests of the SCAN-3A include: 1) a filtered words test in which subjects repeat low-passed monosyllabic words; 2) an auditory figure-ground test in which the subjects repeat monosyllabic words in the presence of a competing babble noise; 3) a competing words test in which subjects repeat two simultaneously presented words; and 4) a competing sentences test in which subjects repeat one of two sentences presented simultaneously to the ears. The SCAN-3A was presented via insert earphones (Etymotic ER-3A) at 50 dB HL.

For all experimental tasks, the R-SPIN stimuli were presented through the compact disc player routed through a diagnostic audiometer (Grason Stadler, Model 61) and played through the speakers in the sound booth. The subject was seated in the center of the sound booth during testing. Audiologic testing equipment used in the study was calibrated according to the appropriate American National Standards Institute standards (ANSI, 2004; 1987). Daily biologic checks were performed to ensure that the equipment was functioning properly.

All experimental testing was completed in one session. Speech recognition testing with the R-SPIN was conducted in unaided and aided conditions. Similarly, questionnaires regarding hearing handicap (HHIA) and listening performance in noise (R-CHAPPS), and listening anxiety were conducted in unaided and aided conditions. Listening anxiety was addressed following completed unaided and aided testing conditions by asking the subject the following question: "Did you experience anxiety during testing?"

The R-SPIN was presented at multiple SNRs. For each SNR level a combined score was obtained for both high and low predictability sentences. Responses to high and low predictability sentences were also scored separately. R-SPIN sentences were presented through speakers with speech presented at 0 degrees azimuth and noise presented at 180 degrees azimuth. The level of the speech was kept constant at 50 dB HL for each condition while the noise level was varied from 60 dB HL to 40 dB HL in 5 dB steps. The range of levels of the background noise provided SNRs of -10 dB, -5 dB, 0 dB, +5 dB, and +10 dB. These SNRs were chosen following a pilot session to determine levels that would allow for a range of performance. A total of 10 R-SPIN conditions were tested (five SNRs for both unaided and aided conditions). The order of R-SPIN list presentation for unaided and aided conditions was randomized for each subject and a complete list of 50 sentences was presented for each SNR condition.

Hearing aid settings:

Following the unaided testing condition, the subjects were fit with hearing aids and real-ear verification was performed to ensure that the hearing aids were meeting the target gain at all frequencies. Hearing aids used in the present study were the Widex Dream 440 Fusion RITE (receiver-in-the-ear) hearing aids. The Dream platform was chosen because it is the most current technology with reported better noise management and sound quality and the 440 level was selected as it is the most advanced level of technology offered in this line. The Fusion style was selected because it is a small size RITE device with easily changed receiver lengths. The hearing aids were programmed similarly to the hearing aids used in the Kuk (2008) study. Specifically, they were programmed to provide 10-15 dB of gain for soft sounds, 5-10 dB of gain for moderate sounds, and 0-5 dB of gain for loud sounds with emphasis on frequencies from 1000-6000 Hz. In RITE style hearing aids, the ear canal is largely open with venting through the dome and low frequency amplification is not able to be provided. Additionally, the hearing aids were programmed with noise reduction enabled and directional microphones activated as this was found to provide the most benefit for the participants in the Kuk (2008) study. No changes to the programming were made to the hearing aids, as none of the subject complained of loudness issues.

Chapter 4

Results

R-SPIN:

Recognition performance on the R-SPIN was poorest in the most difficult SNR condition with performance improving as SNR improved. Subjects also demonstrated better performance on the high predictability R-SPIN target words than on the low predictability target words. Performance neared the ceiling at the +5 dB SNR condition for most subjects. These performance trends were seen both in unaided and aided testing conditions. Figure 1 presents the mean data for R-SPIN performance in each SNR condition for both high and low predictability sentences. When aided, performance improvement was greatest in the most difficult SNR conditions and for low predictability R-SPIN target words.

Prior to statistical analysis, percentage data for the R-SPIN scores for both high and low predictability target words were transformed into rationalized arcsine units (Studebaker, 1985) in order to normalize the error generally encountered with the use of percentage data. A three-way repeated measures analysis of variance (ANOVA) was used to determine if differences in performance existed between the unaided and aided conditions with SNR, hearing aid use, and predictability (high or low predictability R-SPIN target words) as within-subject factors.

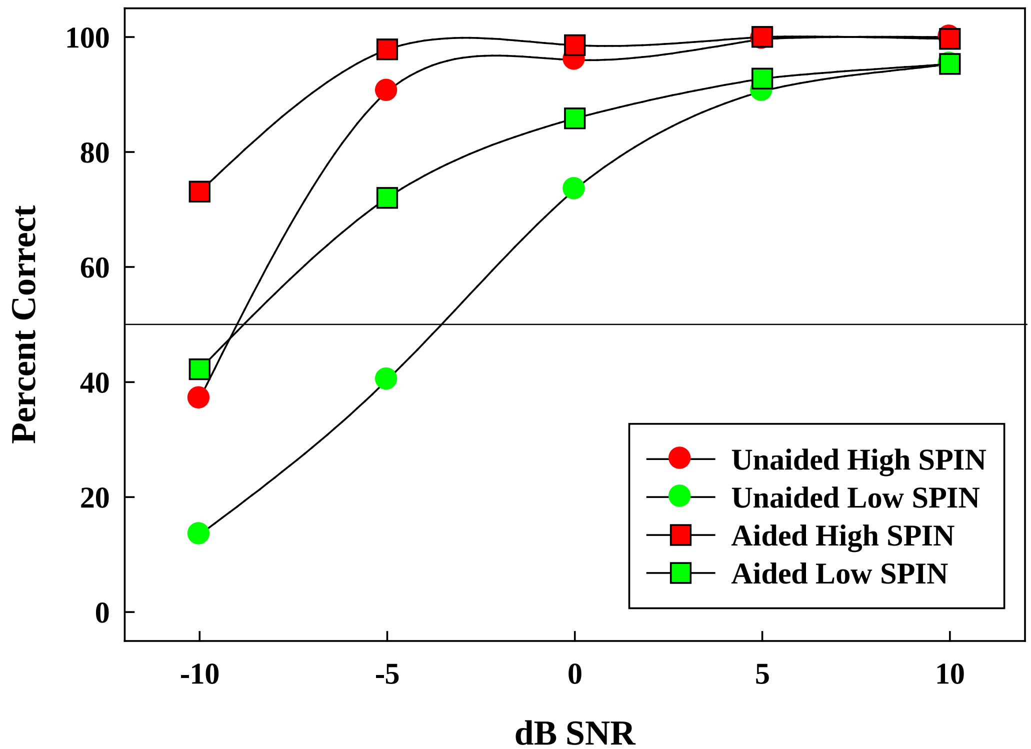

Figure 1. Mean percent correct on R-SPIN for each SNR condition for high predictability (red symbols) and low predictability target words (green symbols) for the aided (squares) and unaided (circles) conditions.

Results revealed significant main effects for SNR [$F(1.8, 17.8) = 221.3$; $p<.05$], hearing aid use [$F(1.0, 10.0) = 9.3$; $p<.05$], and R-SPIN predictability [$F(1.0, 10.0) = 1103.0$; $p<.05$]. For hearing aid use, performance was significantly better for the aided condition compared to the unaided condition. For predictability, performance was significantly better for the high-predictability sentences compared to the low-predictability sentences.

Post-hoc paired samples t-tests with Bonferonni correction were used to evaluate the significant main effect of SNR. Differences in R-SPIN performance were evaluated as a function of hearing aid condition (unaided or aided) for the -10, -5, and 0 dB SNRs. The 5 and 10 dB SNRs were not evaluated due to essentially equal percentage scores on the R-SPIN between hearing aid conditions. The post-hoc paired samples t-tests revealed significant differences in performance due to hearing aid use at the -10 dB SNR condition for high-predictability target words ($t10 = -10.9$; $p<.008$) and low-predictability target words ($t10 = -6.6$; $p<.008$), and for the -5 dB SNR condition for high-predictability target words($t10 = -3.6$; $p = .005$) and low-predictability target words ($t10= 9.7$; $p<.008$). Figure 2 presents the individual data as bivariate plots with percent correct in the unaided condition on the abscissa and percent correct in the aided condition on the ordinate.

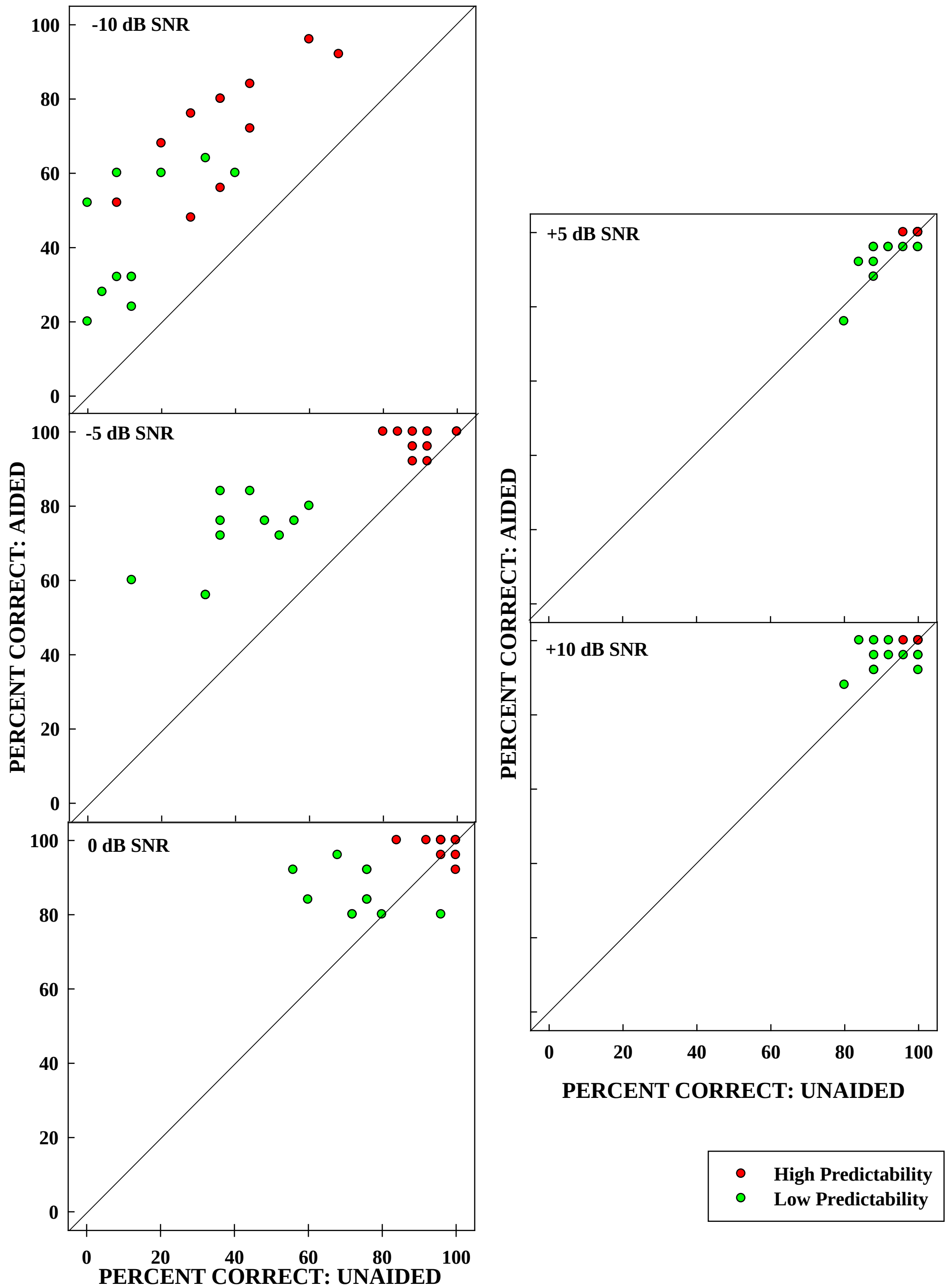

Figure 2. Each box shows a scatterplot of R-SPIN performance on one of the SNR conditions. The y-axis is percent correct on the R-SPIN when aided and the x-axis is percent correct on the R-SPIN unaided. Red points represent performance on the high-predictability target word sentences and green points represent performance on the low-predictability target word sentences.

R-CHAPPS and HHIA:

The R-CHAPPS and HHIA scores were also examined to determine if there was a difference between scores for unaided and aided conditions. Both the R-CHAPPS and the HHIA scores showed improvements in the aided condition when compared to the unaided condition representing a lessened subject perception of listening difficulty or hearing handicap in the aided condition compared to unaided. Average improvement in score from unaided to aided for the R-CHAPPS was 21 points and average improvement in score from unaided to aided for the HHIA was 13.45 points.

A one-way ANOVA was performed for both the R-CHAPPS and the HHIA and revealed that these score improvements were significant for both the R-CHAPPS [$F(1.0, 10.0)= 13.4$; $p<.05$] and for the HHIA [$F=(1,10) = 7.3$; $p<.05$]. Figure 3 shows the R-CHAPPS scores for each subject for the unaided (red bars) and aided (green bars) conditions. Lower (or negative) scores represent a greater degree of listening difficulty. Figure 4 shows the HHIA scores for each subject for unaided (red bars) and aided (green bars) conditions. Higher scores represent greater degrees of handicap.

Anxiety Question:

Participants were also asked a question regarding their experience of anxiety during testing with and without the use of hearing aids. Their responses were transcribed and reviewed. Several participants responded that they did not experience anxiety during testing either with hearing aids or without but stated that they did experience frustration. Some of those participants who reported experiencing frustration expressed that the difficult SNR conditions provided an environment similar to what they experience in daily life. Several participants reported experiencing anxiety during testing which was lessened when wearing hearing aids. Subject responses to the anxiety question are presented in Appendix A.

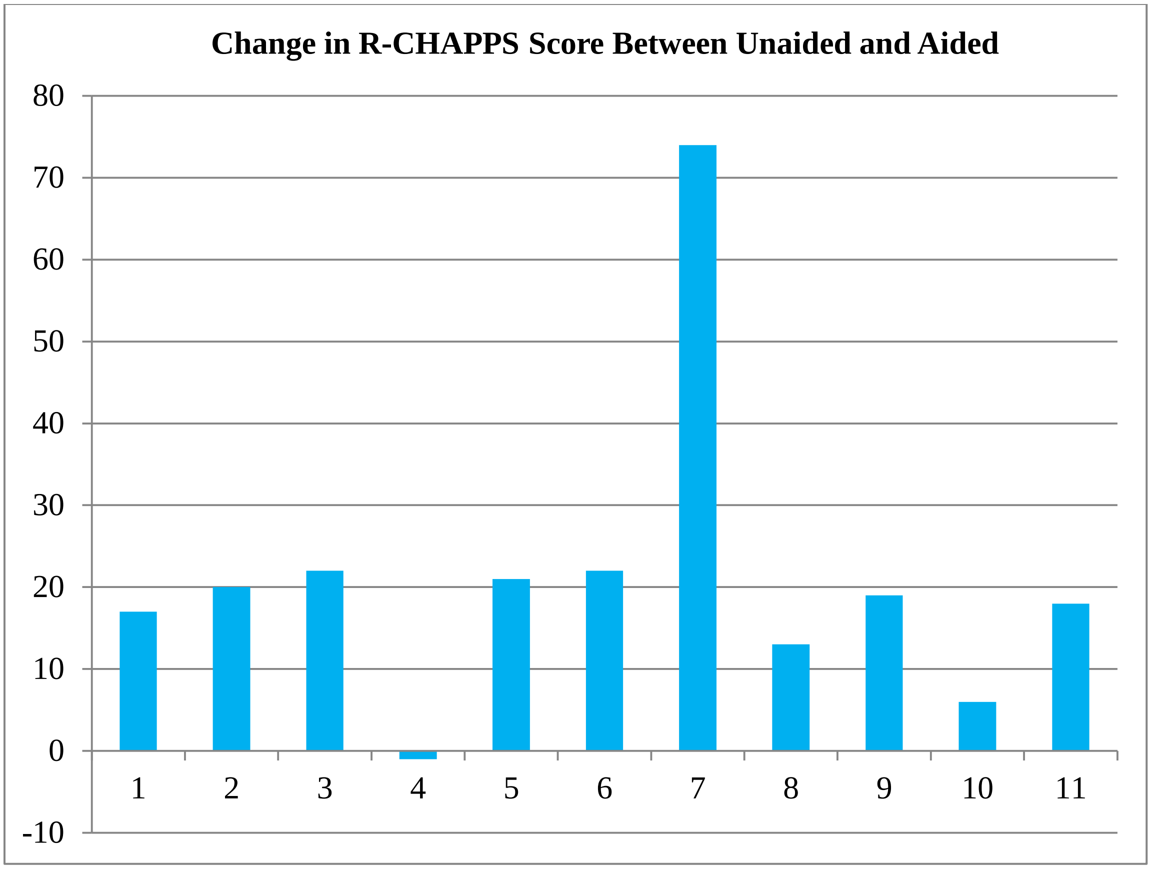

Figure 3 The y-axis is the change in score on the R-CHAPPS between the unaided and aided conditions. The x-axis shows each of the 11 subjects. Each bar shows the change in score from unaided to aided on the R-CHAPPS. Positive numbers represent less listening difficulty reported when aided while negative numbers represent greater listening difficulty reported when aided than when unaided.

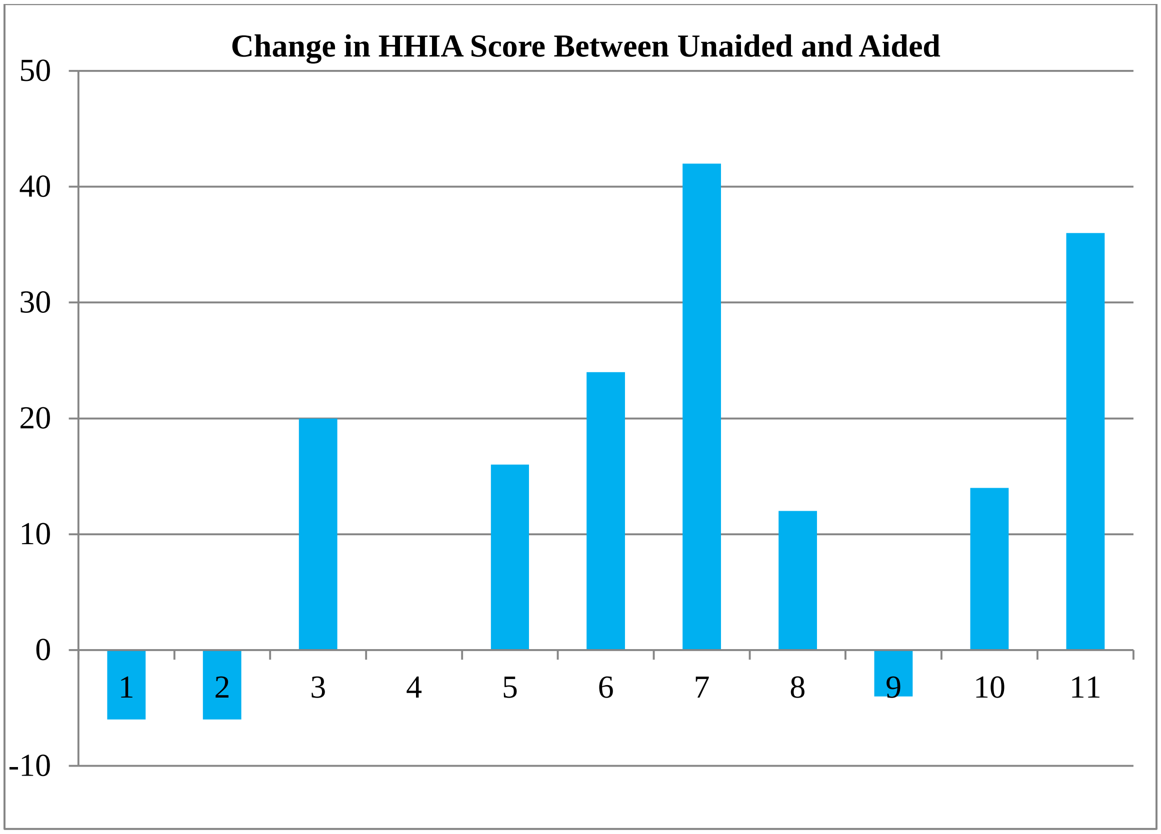

Figure 4. The y-axis is the change in score on the HHIA between the Unaided and Aided conditions. The x-axis shows each of the 11 subjects. Where it appears that there is no blue bar present that subject's score did not change. Positive numbers represent less hearing handicap reported when aided while negative numbers represent more hearing handicap reported when aided than when unaided.

Chapter 5

Discussion

The purpose of the present study was to investigate the potential benefits of mild gain hearing aids equipped with noise reduction and directional microphones in a group of young adults with normal peripheral hearing and complaints consistent with auditory processing difficulties. This was examined objectively through speech in noise testing with and without hearing aids and subjectively through questionnaires administered following speech in noise testing with and without the hearing aids. The results of the study showed significant improvements in performance on speech in noise testing for several SNR conditions and significant improvements on questionnaires addressing listening difficulty and hearing handicap.

The greatest improvements in speech in noise performance were observed in the most difficult listening conditions (-10 dB SNR, -5 dB SNR, and 0 dB SNR) and for the low predictability target words. The improvement in performance for the low predictability target words could be explained by the increased audibility of the final word of the sentence provided by the improvement in SNR from the amplification, directional microphones, and noise reduction. For the high predictability target words the improvement could be attributable to this and to the improved audibility of the contextual clues. In conditions in which the listening situation is extremely challenging contextual cues and predictability are not going to be useful if they are not audible. By making more of the sentence audible to the listeners it allowed them to use the contextual information in the sentence to help predict the target word. These improvements on speech in noise testing are in agreement with the results of Kuk and colleagues' 2008 study investigating the use of hearing aids for children with APD (Kuk et al., 2008). Their data showed significant improvements on performance for speech in noise testing while wearing hearing aids equipped with directional microphones and noise reduction.

Kuk and colleagues (2008) also found that the hearing aid use resulted in improvements on teacher and parent ratings of the children's listening difficulty on a questionnaire (CHAPPS) however their results were not statistically significant. In the present study the subject ratings of listening difficulty on the R-CHAPPS improved and did reach statistical significance. This discrepancy may have been because the questionnaires in the 2008 study by Kuk and colleagues were administered at the beginning of a 6 month trial period and again at the end of that trial. The subjects in the present study only wore hearing aids during the experimental testing session. Therefore the questionnaires in the present study were administered immediately following speech in noise testing with and without hearing aids which resulted in subjects rating their listening difficulty and hearing handicap based off of anticipated performance while wearing the hearing aids in different listening situations.

Subjects in the present study were also asked whether or not they experienced anxiety during the testing with and without the hearing aids. Subjects answered this question in many ways (see Appendix A) but the majority of subjects (9 out of the 11) reported a reduction in anxiety or otherwise improved listening experience when using the hearing aids. Anxiety and fatigue are factors which influence academic or occupational performance, social withdrawal, and psychosocial problems (Keith & Purdy, 2014;

Kreisman et al., 2012). Although they were asked about anxiety, several of the subjects in this study reported decreased frustration and an overall easier listening experience. When asked about anxiety during testing without the hearing aids one subject reported, "…I got really tired and tense" and while wearing the hearing aids commented, "I could I felt like I could just relax and listen and not work so hard." While anxiety was denied with and without the hearing aids, another subject reported, "I really liked wearing these. I feel like it would really help me in class just to be able to focus in on the teacher." Following unaided speech in noise testing yet another subject reported, "Yes, a lot of anxiety. I was really anxious and just wanted to get out of here because I couldn't understand anything". Following aided testing the subject reported no anxiety and stated, "I wish I could take these with me."

The improvements in speech in noise performance in the present study are attributable to the use of mild gain hearing aids with noise reduction and directional microphones. The subjective improvements observed in the HHIA and R-CHAPPS questionnaires may be due to decreased listening effort for the subjects when wearing the hearing aids. Another reason for the improvement on the HHIA and R-CHAPPS could be that as all subjects were first tested in the unaided conditions, their ratings of subjective reduction in listening difficulty and lessened anxiety could be attributable to an increase in their own comfort level with the aided testing session.

Chapter 6

Conclusion

Limitations of current study and future directions:

The current study is limited by a number of factors. The study recruited only a small sample of adults with auditory processing difficulties which makes generalization of the results impossible. Future studies should include a significantly greater number of participants. The short duration of hearing aid use is another limiting factor. It was not feasible to do a long duration study for this capstone project however longer term use of hearing aids is necessary in order to ascertain whether the benefits observed in the test environment carry over into the subjects' daily lives. Additionally the subjects did not have a diagnosis of APD (only complaints and case history consistent with APD) which makes comparisons to studies of subjects with APD difficult. The subjects were recruited for the study based on their complaints and case history. None of the subjects reached the disordered criteria on the SCAN-3A battery administered and only one of the subjects recruited reported a prior diagnosis of APD.

It is important to note however that the SCAN-3A is reported to be insensitive to subtle auditory processing difficulties and individuals who score in the low normal range or borderline normal range have auditory processing skills that are significantly below those of typical adults (Lamoreau, 2011). Case history and subjective reporting through questionnaires reveals difficulties which may not be identified through the SCAN-3A.

Conclusions and clinical implications:

The subjects in this study demonstrated significant improvement in performance during speech in noise testing while using mild gain hearing aids with directional microphones and noise reduction. They also demonstrated significant improvements on ratings of listening difficulty and hearing handicap while using the hearing aids. Additionally they reported less anxiety when wearing the hearing aids during testing. Several of the subjects stated that they would like to try hearing aids outside of the study. These findings suggest that adults with auditory processing difficulties might benefit from the use of mild gain hearing aids with directional microphones and noise reduction. Despite having normal peripheral hearing, adults with auditory processing difficulties should be offered the opportunity to try using mild gain hearing aids to address their difficulties.

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Appendix A: Each subject's verbal responses to the anxiety question which was asked after unaided testing and again after aided testing.

After Unaided Testing: "Did you experience anxiety during testing?"	**After Aided Testing: "Did you experience anxiety during testing?"**
"No."	"No, but I really liked wearing these. I feel like it would really help me in class just to be able to focus in on the teacher. I wish hearing aids weren't so expensive. I would totally get some!"
"Yes. It was very annoying and I just wanted to tell them to shut up."	"A little but because I wasn't sure what to expect, it wasn't bad wearing them and it was way easier than with just me in there listening."
"Yes, a lot of anxiety. I was really anxious and just wanted to get out of here because I couldn't understand anything."	"None at all. I wish I could take these with me."
"A little, more frustration.	"No anxiety, less frustration."
"Frustration, not anxiety."	"Much less frustration."
"Yes, only in the first few. It was similar to real-world experiences."	"No anxiety. The first one was way easier with hearing aids." This subject expressed disbelief that the most difficult aided condition aided was the same as the most difficult unaided condition.
"Yes, similar to when I'm teaching dance class, I got really tired and tense."	"I felt like I could just relax and listen and not work so hard. That was a lot easier, even though the first few were still hard I wasn't as tense and I felt like I could just focus on listening."
"Frustration, it does bother me that I couldn't hear and couldn't move closer."	"I guess not much different, placebo effect maybe because I felt like it was easier."

Appendix A: Each subject's verbal responses to the anxiety question which was asked after unaided testing and again after aided testing.

After Unaided Testing: "Did you experience anxiety during testing?"	**After Aided Testing: "Did you experience anxiety during testing?"**
"Yes, a little. That was really hard especially the first one. "	"Not really different. I felt aware of the hearing aids and it was a little distracting I guess."
"No"	"No"
After first condition unaided subject stated: "I was stressed out. Wow, that was tough. I was tense." After complete testing: "Yes, especially the first one."	After first condition aided subject stated: "Wasn't near as stressful, or as difficult as that first one. I felt like I got most of them right or at least heard part of them." After complete aided testing: "Less anxiety that time. Much easier."

Appendix B: Revised CHAPPS Questionnaire

The subject should answer the following questions by comparing themselves to others of their age and background. For example, all people, to a certain extent, may have difficulties listening and understanding in a noisy room. These questions ask if the individual believes they do more poorly than the average listener in a given listening situation.

RESPONSE CHOICES
Less Difficulty: +1
Same Amount of Difficulty: 0
Slightly More Difficulty: -1
More Difficulty: -2
Considerably More Difficulty: -3
Significantly More Difficulty: -4
Cannot Function At All: -5

Listening Condition: NOISE – If listening in a room where there is background noise such as a TV set, music, others talking, children playing, etc., what is your level of difficulty hearing and understanding compared to the "average" individual?

1. When paying attention	+1	0	-1	-2	-3	-4	-5
2. When being asked a question	+1	0	-1	-2	-3	-4	-5
3. When being given simple instructions	+1	0	-1	-2	-3	-4	-5
4. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5
5. When not paying attention	+1	0	-1	-2	-3	-4	-5
6. When involved with other activities	+1	0	-1	-2	-3	-4	-5
7. When listening in a group	+1	0	-1	-2	-3	-4	-5

Listening Condition: QUIET – If listening in a quiet room, what is your level of difficulty hearing and understanding compared to the "average" individual?

8. When paying attention	+1	0	-1	-2	-3	-4	-5
9. When being asked a question	+1	0	-1	-2	-3	-4	-5
10. When being given simple instructions	+1	0	-1	-2	-3	-4	-5
11. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5
12. When not paying attention	+1	0	-1	-2	-3	-4	-5
13. When involved with other activities	+1	0	-1	-2	-3	-4	-5

Appendix B: Revised CHAPPS Questionnaire

14. When listening in a group	+1	0	-1	-2	-3	-4	-5

Listening Condition: IDEAL – When listening in a quiet room, no distractions, face-to-face and with good eye contact, what is your level of difficulty hearing and understanding compared to the "average" individual?

15. When being asked a question	+1	0	-1	-2	-3	-4	-5
16. When being given a simple instruction	+1	0	-1	-2	-3	-4	-5
17. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5

Listening Condition: MULTIPLE INPUTS – When, in addition to listening, there is some other form of input (visual, tactile, etc.), what is your level of difficulty hearing and understanding compared to the "average" individual?

18. When listening and watching the speaker's face	+1	0	-1	-2	-3	-4	-5
19. When listening and reading material that is also being read out loud by another	+1	0	-1	-2	-3	-4	-5
20. When listening and watching someone provide an illustration such as a drawing, model, etc.	+1	0	-1	-2	-3	-4	-5

Listening Condition: AUDITORY MEMORY/SEQUENCING: If required to recall spoken information, what is your level of difficulty hearing and understanding compared to the "average" individual?

21. Immediately recalling information such as a word, spelling, number	+1	0	-1	-2	-3	-4	-5
22. Immediately recalling simple instructions	+1	0	-1	-2	-3	-4	-5
23. Immediately recalling multiple instructions	+1	0	-1	-2	-3	-4	-5
24. Not only recalling information, but also the order of sequence of the information	+1	0	-1	-2	-3	-4	-5

Appendix B: Revised CHAPPS Questionnaire

25. When delayed recollection (1 hour or more) of simple information (words, word spelling, numbers) is required	+1	0	-1	-2	-3	-4	-5
26. When delayed recollection (1 hour or more) of simple instructions is required	+1	0	-1	-2	-3	-4	-5
27. When delayed recollection (1 hour or more) of multiple Instructions is required	+1	0	-1	-2	-3	-4	-5
28. When delayed recollection (24 hours or more) is required	+1	0	-1	-2	-3	-4	-5

Listening Condition: AUDITORY ATTENTION SPAN – If extended listening required, what level of difficulty is there in being attentive to what is being said?

29. When the listening time is less than 5 minutes	+1	0	-1	-2	-3	-4	-5
30. When listening time is 5 to 10 minutes	+1	0	-1	-2	-3	-4	-5
31. When listening time is over 10 minutes	+1	0	-1	-2	-3	-4	-5
32. When listening in a quiet room	+1	0	-1	-2	-3	-4	-5
33. When listening in a noisy room	+1	0	-1	-2	-3	-4	-5
34. When listening first thing in the morning	+1	0	-1	-2	-3	-4	-5
35. When listening at the end of the day, before supper time	+1	0	-1	-2	-3	-4	-5
36. When listening in a room where there are also visual distractions	+1	0	-1	-2	-3	-4	-5

Appendix C: HHIA Questionnaire

HEARING HANDICAP INVENTORY FOR ADULTS (HHIA)

INSTRUCTIONS: The purpose of the scale is to identify the problems your hearing loss may be causing you. Check YES, SOMETIMES, or NO for each question. DO NOT skip a question if you avoid a situation because of your hearing problem.

		Yes (4)	Sometimes (2)	No (0)
S-1	Does a hearing problem cause you to use the phone less often than you would like?			
E-2	Does a hearing problem cause you to feel embarrassed when meeting new people?			
S-3	Does a hearing problem cause you to avoid groups of people?			
E-4	Does a hearing problem make you irritable?			
E-5	Does a hearing problem cause you to feel frustrated when talking to members of your family?			
S-6	Does a hearing problem cause you difficulty when attending a party?			
S-7	Does a hearing problem cause you difficulty hearing/understanding coworkers, clients, or customers			
E-8	Do you feel handicapped by a hearing problem?			
S-9	Does a hearing problem cause you difficulty when visiting friends, relatives, or neighbors?			
E-10	Does a hearing problem cause you to feel frustrated when talking to coworkers, clients or customers?			
S-11	Does a hearing problem cause you difficulty in the movies or theater?			
E-12	Does a hearing problem cause you to be nervous?			
S-13	Does a hearing problem cause you to visit friends, relatives, or neighbors less often than you would like?			
E-14	Does a hearing problem cause you to have arguments with family members?			
S-15	Does a hearing problem cause you difficulty when listening to TV or radio?			
S-16	Does a hearing problem cause you to go shopping less often than you would like?			
E-17	Does any problem or difficulty with your hearing upset you at all?			
E-18	Does a hearing problem cause you to want to be by yourself?			

Appendix C: HHIA Questionnaire

		Yes	Sometimes	No
S-19	Does a hearing problem cause you to talk to family members less often than you would like?			
E-20	Do you feel that any difficulty with your hearing limits or hampers your personal or social life?			
S-21	Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?			
E-22	Does a hearing problem cause you to feel depressed?			
S-23	Does a hearing problem causeyou to listen to TV or the radio less often than you would like?			
E-24	Does a hearing problem cause you to feel uncomfortable when talking to friends?			
E-25	Does a hearing problem cause you to feel left out when you are with a group of people?			