Mild-Gain Hearing Aids as a Treatment for Adults with Self-Reported Hearing Difficulties

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Abstract

Background: There is a growing body of evidence demonstrating self-reported hearing difficulties (HD; i.e., substantial difficulty in understanding speech in complex listening situations) in adults with normal pure-tone sensitivity. Anecdotally, some audiologists have tried personal mild-gain amplification as a treatment option for adults with HD. In 2008, Kuk and colleagues reported positive results of a mild-gain hearing aid trial for children with auditory processing disorders. To date, however, there have been no studies investigating the benefit of mild-gain amplification to treat HD in adults with normal audiograms.

Purpose: The effectiveness of a four-week trial with mild-gain amplification for adults with self-reported HD and clinically normal hearing sensitivity was investigated.

Research Design: Two participant groups with normal pure-tone audiograms (thresholds ≤20 dB HL 250–8000 Hz) were recruited to study the effects of self-reported HD on hearing handicap, self-perceived auditory processing difficulties, and performance on a speech-in-noise task. Furthermore, the benefit of mild-gain amplification was examined after a four-week hearing aid trial on self-perceived hearing handicap and auditory processing difficulties, and performance on an aided speech-in-noise task. Effects were analyzed using a mixed-model repeated measures analysis of variance. Posthoc analyses were performed for each significant main effect.

Study Sample: Thirty-nine participants participated in two groups. Twenty normal hearing adults (19–27 yr) without complaints of HD were recruited as a control group. Nineteen normal hearing adults (18–58 yr) with self-reported HD were recruited for the mild-gain hearing aid trial.

Data Collection and Analysis: Subjective complaints of HD were assessed with two questionnaires (the Hearing Handicap Inventory for Adults [HHIA] and the Auditory Processing Questionnaire [APQ]) and an auditory processing test battery (SCAN:3-A, dichotic digit recognition, gaps-in-noise test, and the 500-Hz masking level difference). Speech-in-noise abilities were assessed before and after hearing aid trial using the Revised Speech Perception in Noise Test (R-SPIN) at multiple signal-to-noise ratios. Hearing aid use and impressions during the hearing aid trial were recorded.

Results: Results demonstrated that participants with HD perceived significantly greater hearing handicap (HHIA) and greater self-perceived auditory processing difficulties (APQ) than the control group. Participants with HD performed significantly poorer on the R-SPIN relative to controls, especially for low-predictability items. Results of the hearing aid trial for participants with HD revealed significant improvements in hearing handicap, self-perceived auditory processing difficulties, and speech-in-noise performance relative to pre-hearing aid trial measures. The hearing aids were well tolerated by the majority of participants with HD , with most of them wearing the hearing aids an average of 1–4 h per day.

Conclusions: The results from the present study suggest that adults who present with complaints of HD even in the presence of normal hearing sensitivity represent a unique population that warrants further

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evaluation beyond the standard hearing test. Furthermore, results from the hearing aid trial suggest that mild-gain amplification is a viable treatment option for at least some individuals with HD.

Key Words: auditory processing, hearing aids, speech perception

Abbreviations: ANOVA = analysis of variance; APD = auditory processing disorder; APQ = Auditory Processing Questionnaire; CHAPS = Children's Auditory Performance Scale; CI = confidence interval; DDT = Dichotic Digits Test; FM = frequency modulation; GIN = Gaps-in-Noise; HD = hearing difficulties; HHIA = Hearing Handicap Inventory for Adults; MLD = masking level difference; OAD = obscure auditory dysfunction; OSU = Ohio State University; R-SPIN = Revised Speech Perception in Noise Test; SNR = signal-to-noise ratio; TBI = traumatic brain injury

INTRODUCTION

Individuals with suprathreshold auditory deficits and self-reported hearing complaints in the presence of normal pure-tone sensitivity (i.e., a normal clinical audiogram) represent a unique yet not uncommon adult clinical population (Rappaport et al, 1993). Nor is this phenomenon a recent clinical issue, with the first description by Kopetzky in 1948 (Hinchcliffe, 1992). In more recent decades, numerous reports have been published describing an adult population with both self-reported complaints about their hearing in the presence of background noise and suprathreshold auditory deficits (e.g., speech understanding deficits, temporal resolution deficits, etc.) yet pure-tone hearing thresholds in the normal range. Terms used to describe this population include central presbycusis (Welsh et al, 1985), auditory disability with normal hearing (Stephens and Rendell, 1988), obscure auditory dysfunction (OAD; Saunders and Haggard, 1989; Higson et al, 1994), King–Kopetzky syndrome, so named for P.F. King and S.J. Kopetzky who published early reports (i.e., 1948 and 1954) on this population (Hinchcliffe, 1992; Zhao and Stephens, 1996a), auditory dysacusis (Jayaram et al, 1992), central auditory processing disorder (Jerger et al, 1990; Rodriguez et al, 1990; Bamiou et al, 2000), idiopathic discriminatory dysfunction (Rappaport et al, 1993), hidden hearing loss (Schaette and McAlpine, 2011), and hearing difficulties (HD; Tremblay et al, 2015).

It is difficult to know the true prevalence of adults with self-reported HD and normal pure-tone audiograms. Prevalence estimates range from 5% for individuals seeking help for "hearing problems" (Saunders and Haggard, 1989) to 12% in a population-based cohort of adults 21–67 yr of age with normal pure-tone audiograms, yet they reported hearing problems based on four questions from the Hearing Handicap Inventory for Adults (HHIA; Newman et al, 1990) (Tremblay et al, 2015). Similarly, 3–10% of older adults 48–92 yr of age with normal pure-tone audiograms reported clinically significant hearing handicap (scores >8) as measured by the Hearing Handicap Inventory for the Elderly Screening questionnaire (Ventry and Weinstein, 1983; Wiley et al, 2000). The prevalence of self-reported HD and normal pure-tone audiograms is estimated to be much greater among adults with traumatic brain injury (TBI), from 16% in veterans with a history of mild TBI (Oleksiak et al, 2012) to 58% in adults 25–59 yr of age with a history of closed head injury (Bergemalm and Lyxell, 2005). The number of individuals presenting with HD and normal pure-tone audiograms, therefore, is not clinically insignificant. In fact, individuals with HD commonly self-refer for hearing or medical evaluations indicating that their symptoms are severe enough to warrant help-seeking behavior (Saunders and Haggard, 1989; Zhao and Stephens, 1996a; Tremblay et al, 2015).

Suprathreshold auditory deficits have also been shown to occur in various populations of adults with normal pure-tone audiograms, including middle-aged adults (Bamiou et al, 2000; Grose et al, 2006; Ross et al, 2007; Helfer and Vargo, 2009; Leigh-Paffenroth and Elangovan, 2011), older adults (Rodriguez et al, 1990; Dubno et al, 2002; Hannula et al, 2011), individuals with known lesions of the central auditory nervous system, including auditory neuropathy spectrum disorder (Rappaport et al, 1994; Musiek et al, 2005; Vignesh et al, 2016), individuals with a history of TBI (Meyers et al, 2002; Musiek et al, 2004; Bergemalm and Lyxell, 2005; Lux, 2007; Gallun et al, 2012), individuals with a history of noise exposure (Kumar et al, 2012), and individuals with subjective HD (Saunders and Haggard, 1989; Higson et al, 1994; Zhao and Stephens 1996b; Stephens and Zhao, 2000). For example, Saunders and Haggard tested 20 adults with OAD (i.e., HD) on a speech-in-noise task at a +5.5 dB signal-to-noise ratio (SNR). Participants with OAD performed significantly worse than age-matched control participants. Similarly, Stephens and Zhao (2000) examined Bamford Kowal Bench sentence recognition performance in speech-shaped noise at 0 and −5 dB SNR in 110 adults with King–Kopetzky syndrome (i.e., HD). Stephens and Zhao found that the majority of participants with King–Kopetzky syndrome exhibited abnormally poor Bamford Kowal Bench sentence recognition relative to a normal control group. In contrast, Tremblay et al (2015) did not find significant differences in monosyllabic word recognition-in-noise between their participants with and without HD. The lack of speech-in-noise deficits for participants with HD found by Tremblay et al may be because of the +8 dB SNR. In other words, the task may have been too easy to elicit performance deficits.

The impact of noise exposure on suprathreshold auditory abilities has received considerable attention in recent years. Work in the animal model has demonstrated evidence of "cochlear synaptopathy," in which spiral ganglion nerve cell degeneration persists after noise exposure even when recovery of hair cell function is observed (Kujawa and Liberman, 2009). In humans, it is thought that this cochlear synaptopathy would potentially result in suprathreshold auditory deficits in the presence of a normal pure-tone audiogram (Liberman et al, 2016). Data from Kumar and colleagues (2012) support this hypothesis. Kumar et al tested speech recognition in a multitalker babble at a −5 dB SNR in a group of normal hearing (thresholds ≤25 dB HL) middle-aged train drivers exposed to occupational noise for a minimum of 10 yr and an age-matched non-noise exposed control group. Results demonstrated significantly poorer speech recognition performance for the group with a history of occupational noise exposure. Similar results were reported by Liberman et al in a group of college students with a self-reported history of exposure to noise.

Adults with a history of TBI have been known to present clinically with HD in the presence of a normal pure-tone audiogram. In addition, research studies have confirmed the presence of suprathreshold auditory deficits for adults with a history of TBI, including (a) deficits on one or more behavioral tests of central auditory processing (Musiek et al, 2004; Turgeon et al, 2011; Gallun et al, 2012); (b) deficits on competing sentences (Bergman et al, 1987); (c) deficits in dichotic speech recognition, with greater deficits in adults with greater severity of TBI (Levin et al, 1989; Meyers et al, 2002); and (d) longer than normal latencies and lower than normal amplitudes of the late-latency P300 auditory evoked potential (Gallun et al, 2012). Individuals with known brain lesions or injuries such as TBI can present with normal auditory and cognitive behaviors in quiet and structured settings. When presented with noisy, complex, and distracting environments, however, the same individuals can break down (Bergman et al, 1987; Lux, 2007), leading to self-perceived HD.

Because results of pure-tone threshold testing are normal for adults with HD, they are typically diagnosed as having "normal hearing" and counseled accordingly. Unfortunately, suprathreshold auditory measures such as speech-in-noise testing or measures of central auditory processing are not undertaken in light of a normal audiogram. A missed diagnosis of suprathreshold auditory deficits among adults with HD because of normal audiometric test results can lead to a reduction in quality of life, including mental health issues such as depression (Higson et al, 1994; Saito et al, 2010; Tremblay et al, 2015) and emotional distress (Gopinath et al, 2012). For instance, Tremblay et al (2015) assessed the prevalence of depressive symptoms using the Center for Epidemiological Studies-Depression questionnaire (Radloff, 1977), a 20-item self-report depression scale used to probe symptoms such as restless sleep, poor appetite, and feeling lonely. Participants in the HD group, as compared with a control group, were more likely to have Center for Epidemiological Studies-Depression total scores above the recommended cutoff indicating a greater prevalence of depression. Therefore, individuals with HD are at a greater risk for experiencing a negative impact on their psychosocial functioning and reduced quality of life (Tremblay et al, 2015).

There is little research evaluating the treatment options for adults with subjective HD. Baran (2002) described management techniques for adults with auditory processing disorders (APDs), including improving the quality of the speech signal, auditory training, and language and cognitive training. Improving the quality of the signal is a bottom-up approach that can be accomplished through environmental management (e.g., reduce background noise) or technology. The most common technological approach to treating HD (or APD) among adults is with the use of an FM (frequency modulation) system to improve the SNR. The use of FM systems among adults, however, is complicated by the fact that they require both the listener and the speaker to actively and correctly use the device (Kuk et al, 2008), and few, if any, adults chose to continue FM use beyond a study trial period, even in the face of significant benefit (Jerger et al, 1990; Boothroyd, 2004; Lewis et al, 2005).

Another potential technological treatment option for adults with subjective HD is the use of personal-level devices such as mild-gain hearing aids. Anecdotally, some audiologists have tried personal mild-gain hearing aids as a treatment option for individuals with HD. The rationale for using personal mild-gain hearing aids is to provide minimal gain (e.g., 5–10 dB) for soft to conversational inputs in the mid- to high-frequencies to enhance soft consonants in speech. Mid- to high-frequency consonants (e.g., /f/, /v/, /th/, /s/) are often low in intensity and are easily masked by background noise (Miller and Nicely, 1955; Dubno and Levitt, 1981). In addition, the use of adaptive multiband directional microphones can serve to improve the SNR by reducing input from behind or the side of the listener, while preserving sound input from the front (Bentler, 2005; Ricketts, 2005). Finally, multiband noise reduction algorithms can improve listening comfort for the listener, particularly in noisy environments (Ricketts and Hornsby, 2005; for a review, see Bentler, 2005). Evidence of the benefit of mild-gain amplification for adults with HD and normal pure-tone audiograms, however, is lacking. To date, one study has been published in the pediatric population investigating the benefit of mild-gain amplification to treat APD in children (Kuk et al, 2008).

Fourteen children with normal pure-tone audiograms and an APD diagnosis were fit with bilateral mild-gain, open-fit hearing aids. Auditory processing abilities were measured objectively using a monosyllabic word recognition-in-noise task, and assessed subjectively via questionnaire (Children's Auditory Performance Scale [CHAPS]; Smoski et al, 1998) completed by their parents and teachers in both the unaided and aided conditions. Speech recognition was evaluated in four separate sessions: at the initial visit, two weeks postfitting, three months postfitting, and six months postfitting. Results revealed that hearing aids plus omnidirectional microphones did not improve speech recognition-in-noise performance. Results for hearing aids plus directional microphones and noise reduction, however, revealed significant improvements in speech recognition-in-noise performance when compared with the unaided condition. In addition, the parents and teachers of the children found some areas of auditory processing as measured by the CHAPS to improve with the use of the hearing aids. The results from Kuk et al (2008) were the first to demonstrate that the use of mild-gain, open-fit hearing aids may prove beneficial for at least some children with APD.

The present study was undertaken as a proof of concept study based on pilot data from our laboratory to demonstrate the potential benefit of mild-gain hearing aids to improve subjective hearing handicap and speech-in-noise performance in adults with HD. In an unpublished Capstone Project, Moore (2015) demonstrated significant improvements in speech recognition-in-noise performance with the use of mild-gain hearing aids for a group of 11 adults (20–40 yr of age) with HD. Each participant was fit binaurally with mild-gain, open-fit hearing aids with directional microphones and noise reduction enabled, and 5–10 dB of gain for soft inputs. Speech recognition-in-noise ability was assessed with the Revised Speech Perception in Noise Test (R-SPIN; Bilger, 1984; Bilger et al, 1984) conducted at five SNRs (−10, −5, 0, 5, and 10 dB SNR) in both unaided and aided conditions. All testing was completed in one session. Moore found that participants exhibited significantly better R-SPIN performance with the use of mild-gain hearing aids relative to the unaided condition for both high- and low-predictability R-SPIN sentences at the −10 and −5 dB SNRs. The pilot data from Moore suggested that speech recognition-in-noise can be improved for adults with subjective HD with the use of personal mild-gain amplification. The pilot data from Moore, however, are limited in that the participants only wore the hearing aids in the laboratory during testing. The purpose of the present study, therefore, was to evaluate the potential benefit of a four-week trial of mild-gain hearing aids in a group of adults with HD and suprathreshold auditory deficits in the presence of a normal pure-tone audiogram. A secondary purpose of the present study was to confirm the presence of hearing handicap and speech-in-noise deficits for adults with HD relative to a control group.

METHODS

The present study was approved by the Biomedical Sciences Institutional Review Board at The Ohio State University (OSU). Subjects were recruited through the Department of Speech and Hearing Science Hearing Clinic, posted flyers and online advertisements on the OSU campus and surrounding community of Columbus, OH. Advertisements specifically asked for listeners with trouble understanding speech in competitive listening environments. All participants were compensated for their time, and were given the option of purchasing the hearing aids at a discount on completion of the study. All equipment (audiometer, tympanometer, and hearing aid test system) was calibrated according to the appropriate American National Standards Institute standards (ANSI, 1987, 1997, 2003, 2004).

Participants

A total of 39 participants in two groups were recruited for the present study. The control group included 20 young adults (2 males and 18 females), 19–27 yr of age (mean age = 21.8 yr), with normal hearing sensitivity (pure-tone thresholds ≤25 dB HL 250–8000 Hz) without any self-reported HD. The experimental group included 19 adults with self-reported HD. Two participants with HD withdrew (#1 and #11; participant #1 felt that the hearing aids were too loud and withdrew from the study, and participant #11 lost a hearing aid mid-way through the trial and was therefore withdrawn) from the study, leaving a total of 17 participants with HD (5 males and 12 females) of 18–58 yr old (mean age = 30.8 yr) who completed the hearing aid trial. Participants with HD had normal pure-tone sensitivity (thresholds ≤25 dB HL 250–8000 Hz; one participant with HD had a 30 dB HL threshold at 500 Hz in one ear). Pure-tone threshold testing was completed before and after the hearing aid trial. None of the participants with HD experienced more than a 5 dB elevation in pure-tone thresholds at any frequency between pre- and postfitting. Air conduction thresholds were within 10 dB of bone conduction thresholds for all participants. Inclusion criteria for both groups included (a) normal otoscopy, (b) tympanometry within normal limits (Wiley et al, 1996; Roup et al, 1998), (c) no recent history of middle-ear pathology, (d) no family history of hearing loss, and (e) native speakers of English. Additional inclusion criteria included a score ≥20 on the HHIA (Newman et al, 1990) for the HD group, and an HHIA score ≤18 for the control group.

Materials

Self-reported HD were measured using the HHIA and the Auditory Processing Questionnaire (APQ). The HHIA is a 25-item questionnaire that addresses the social and emotional consequences of a "hearing problem." Responses to the items include yes (4 points), sometimes (2 points), and no (0 points). Scores range from 0 to 100, with higher scores indicating greater hearing handicap (Newman et al, 1990). The APQ is based on the CHAPS questionnaire (Smoski et al, 1998) which is completed by a parent or teacher on behalf of a child. All questions and listening conditions were kept the same, only the CHAPS instructions and scoring were revised to be appropriate for an adult (Lamoreau, 2011). The APQ assesses the level of difficulty an individual experiences in various listening conditions on a 7-point Likert scale where 0 = never and 6 = always. There are a total of 36 questions across six listening conditions, including noise, quiet, ideal, multiple inputs, auditory memory/sequency, and auditory attention span. Scores range from 0 to 216 with lower scores indicating few self-perceived auditory processing difficulties.

Auditory processing abilities were measured in the HD group with a battery of tests including the SCAN-3:A (Keith, 2009), the 500-Hz masking level difference (MLD; Wilson et al, 2003) on the *Speech Recognition and Identification Materials, Disc 4.0* (Department of Veterans Affairs, 2006), the Gaps-in-Noise (GIN) Test (Musiek et al, 2005), and the Dichotic Digits Test (DDT; Strouse and Wilson, 1999) on the *Tonal and Speech Materials for Auditory Perceptual Assessment* disc (Department of Veterans Affairs, 1998).

SCAN-3:A

The SCAN-3:A is a commercially available auditory processing test used for the screening and diagnosis of APD in adults (Keith, 2009). The SCAN-3:A consists of four diagnostic subtests which evaluate different areas of auditory processing including filtered words, auditory figure-ground, competing words, and competing sentences. Raw scores for each subtest are converted to scaled scores and then categorized as normal, borderline, or disordered. An auditory-processing composite score is then calculated using the sum of scaled scores for each diagnostic subtest. The auditory-processing composite score is also categorized as normal, borderline, or disordered.

500-Hz Masking Level Difference

The 500-Hz MLD (Wilson et al, 2003) is a measure of binaural release from masking and represents the auditory system's ability to make use of interaural phase differences between the two ears. Briefly, the stimuli consist of a 500-Hz tone and a 500-Hz narrowband noise recorded on separate channels. The 500-Hz tone and 500-Hz narrowband of noise are presented in two conditions: (a) the S_0N_0 condition, where the tone and noise are in phase in both ears and (b) the $S_\pi N_0$ condition, where the tone is 180° out of phase between the ears and the noise is in phase in both ears. Participants were instructed to verbally respond "yes" or "no" if they heard a tone after each stimulus presentation. The Spearman-Kärber method (Finney, 1952) was used to determine S_0N_0 and $S_\pi N_0$ thresholds, and the MLD was calculated as the difference in threshold between the S_0N_0 and $S_\pi N_0$ conditions.

GIN Test

The GIN Test (Musiek et al, 2005) is a clinical measure of temporal resolution (Shinn et al, 2009) in which listeners identify when a gap is present in a noise burst. The test consists of 36 noise bursts, with zero to three gaps per noise burst. Gap lengths vary from 2 to 20 msec. The GIN is administered to each ear individually. The GIN is scored in two ways: percent correct (percent of correctly identified gaps) and gap-threshold (smallest gap detected at least four of six times). Abnormal performance is characterized by a percent correct value of $<$54% and/or a gap-threshold of $\geq$7 msec (Musiek et al, 2005).

DDT

The DDT (Strouse and Wilson, 1999) is an assessment of binaural integration and separation. The DDT includes 1, 2, and 3 pairs of dichotic digits (1–10, excluding 7) that are presented simultaneously to the right and left ears. The DDT is administered in two conditions: free recall and directed recall. In the free recall condition, listeners were asked to repeat as many digits as they recall from both ears. Directed recall requires the listener to repeat only the numbers from the directed ear (i.e., for directed right, the listener repeats the digits presented to the right ear, while ignoring the digits presented to the left ear). Percent correct recognition performance was calculated for each ear, in each condition, and for 1-, 2-, and 3-pair digits individually. Percentage scores were then compared with normative age-based 99.7% confidence intervals (CIs) to determine if performance is within normal limits or abnormal (Strouse and Wilson, 1999).

R-SPIN

The R-SPIN (Bilger, 1984; Bilger et al, 1984) was used to measure unaided and aided speech recognition in a multitalker babble. The R-SPIN is composed of eight lists of high-predictability and low-predictability sentences. Each list of 50 sentences contains 25 high and 25 low-predictability sentences. High-predictability sentences are such that the final word can be reasonably predicted based on the content of the sentence, whereas low-predictability sentences are such that the final word cannot be reasonably predicted based on the sentence content. The listener is required to verbally repeat the last word in each sentence.

Procedures

Auditory Tests

All tests in the auditory processing test battery were administered in a double-wall sound booth (IAC, Model 403 ATR) and were presented from a compact disc player (Sony CD375) through a two-channel audiometer (Grason Stadler, Model 61) via insert earphones (EAR Tone 3A). The SCAN-3:A, GIN, and DDT were presented at 50 dB HL, and the 500-Hz MLD was presented at 70 dB HL (per Wilson et al, 2003). R-SPIN testing was administered with the same setup as earlier with the exception that the test was presented in the sound field. Participants were seated in the center of the sound booth 52 inches from the front and back speakers. R-SPIN sentences were presented from the front speaker at 0° azimuth, and the multitalker babble was presented from the back speaker at 180° azimuth. For both unaided and aided testing, the multitalker babble was presented at 50 dB HL, and the level of the R-SPIN sentences was varied to create four SNRs: −12, −8, −4, and 0 dB SNR. The R-SPIN sentence lists and the four SNRs were randomized across participants to avoid list and SNR effects. Participants were instructed to repeat the final word of the sentence. Responses were scored as correct or incorrect and a percent correct was calculated for high- and low-predictability sentences at each SNR.

Study Sessions

Control participants participated in a single test session in which they completed the HHIA and APQ questionnaires, as well as the R-SPIN testing. The HD group participated in three sessions. Session 1 determined candidacy (HHIA ≥20), as well as completion of the auditory processing test battery. Session 2 consisted of unaided R-SPIN testing and the hearing aid verification and orientation for the participants with HD. Session 3 was scheduled four weeks after Session 2. During Session 3, participants with HD completed aided questionnaires (HHIA and APQ) and aided R-SPIN testing using the same setup as the unaided testing. The hearing aids were returned at the end of Session 3. Participants with HD who were interested in purchasing the hearing aids after the trial were scheduled with the OSU Speech and Hearing Clinic for a hearing aid evaluation.

Hearing Aids

During Session 2, participants with HD were fit bilaterally with receiver-in-the-canal, wide dynamic range compression hearing aids (Widex Dream 440 Fusion) with open domes. Receiver-in-the-canal aids with open domes were chosen to ensure maximum comfort with minimal occlusion of the ear canal. Adaptive multiband directional microphones and multiband noise reduction were enabled. The noise reduction feature engages when a low-frequency, minimally fluctuating signal is detected. In addition, multiband directionality and noise reduction engage when a poor SNR is detected within a given frequency band, including mid- to high-frequency bands. Widex also employs “speech enhancer” technology which serves to enhance spectral peaks to achieve a better SNR.

The hearing aids were programmed to provide 5–10 dB of insertion gain between 1000 and 4000 Hz for soft and conversational inputs and no gain for loud inputs using Widex Compass GPS software. Compression thresholds are automatically set in the Widex software (Compass GPS frequency-output screen) as gain is adjusted for the 15 frequency channels. For the participants with HD, compression thresholds ranged from 28 to 35 dB SPL for soft inputs. Hearing aid insertion gain was verified using real-ear probe-microphone measures (Frye Fonix 7000) for two inputs: 65 and 90 dB SPL. Average insertion gain for a 65 dB SPL input between 1000–4000 Hz is presented in Table 1. Maximum power output did not exceed 100 dB SPL for any participant. Electroacoustic front-to-back ratio verification of the multiband directionality confirmed a reduction in the level of noise relative to the speech signal between 1000 and 4000 Hz.

An orientation to the hearing aids was conducted after the hearing aid programming and verification. Participants with HD were instructed on use and care of the hearing aids. A hearing aid diary was given to each participant with HD to record hearing aid usage (# of hours, listening environments) and perceived benefit (hearing aids helped a lot, a little, not at all, or made listening worse) for each day of the four-week trial. Each participant with HD was asked to wear the hearing aids for a minimum of 4 h per day in a variety of listening environments.

Table 1. Mean insertion Gain (and Standard Deviations [SD]) for 1000–4000 Hz for Right and Left Ears

	Frequency in Hz			
	1000	2000	3000	4000
Mean (SD)				
Right ear	3.6 (1.4)	9.4 (2.6)	11.1 (2.8)	7.2 (3.1)
Left ear	3.6 (1.9)	10.2 (2.4)	11.5 (2.5)	7.6 (3.1)

RESULTS

Auditory Processing Test Battery: HD Group

Sixteen out of 17 (94%) participants with HD exhibited abnormal performance or performance below the normal range on at least one of the auditory processing test battery measures (MLD, SCAN-3:A, GIN, and DDT free and directed recall). Abnormal performance or performance below the normal range was defined as (a) an MLD ≤8 dB (Wilson et al, 2003); (b) SCAN-3: A composite score in the abnormal range (Keith, 2009); (c) 1-, 2-, or 3-pair dichotic digit recognition performance below the lower cutoff of the 99.7% CI for free or directed recall conditions (Strouse and Wilson, 1999); and (d) GIN percent correct <54% or a gap-threshold ≥7 msec (Musiek et al, 2005). The number (and percent) of participants having HD with performance below the normal range for each auditory processing test are presented in Table 2. Of the 17 participants with HD, two (12%) had abnormal MLD thresholds and SCAN-3:A results, seven (41%) exhibited below normal performance for dichotic digits in the free recall condition, nine (53%) exhibited below normal performance for dichotic digits in the directed recall condition, and nine (53%) had abnormal GIN results. R-SPIN results for each SNR are also included in Table 2. Abnormal performance on the R-SPIN was defined as recognition performance below the lower cutoff of the 99.7% CI for the control group at each SNR. The 99.7% CI was calculated as the mean percent correct ± three standard errors. All seventeen participants with HD exhibited below normal R-SPIN recognition performance for at least two SNRs for both high- and low-predictability sentences. As seen in Table 2, the percentage of participants with HD exhibiting R-SPIN recognition performance below the lower cutoff of the 99.7% CI ranged from 71% to 88% across SNRs for high- and low-predictability sentences.

Table 2. Number and Percent of Participants with HD with Performance below the Normal Range for Each Test in the Auditory Processing Battery

	Participants with Performance below the Normal Range	
Auditory Test	Number	Percentage
MLD	2	12%
SCAN-3:A	2	12%
DDT—free recall	7	41%
DDT—directed recall	9	53%
GIN	9	53%
R-SPIN high predictability		
12 dB SNR (<39.2%)	15	88%
8 dB SNR (<71.2%)	14	82%
4 dB SNR (<91.3%)	14	82%
0 dB SNR (<97.6%)	13	76%
R-SPIN low predictability		
12 dB SNR (<23.2%)	12	71%
8 dB SNR (<46.3%)	15	88%
4 dB SNR (<66.9%)	15	88%
0 dB SNR (<79.6%)	15	88%

Notes: The number of participants having HD with R-SPIN recognition performance below the lower cutoff of the 99.7% CI for the control group is included for each SNR: −12, −8, −4, and 0 dB. The lower cutoff percentage is included in parentheses for each SNR.

Control versus HD: Questionnaires

Mean HHIA and APQ scores and standard deviations for the control and HD groups are presented in Table 3. As seen in Table 3, mean HHIA scores for the HD group (38.4) were greater than the scores for the control group (0.1). A one-way analysis of variance (ANOVA) confirmed that the HD group demonstrated significantly greater hearing handicap than the control group ($F_{1,\ 35} = 73.0$; $p < 0.05$). Similarly, mean APQ scores were greater for the HD group (81.5) than the control group (24.5). A one-way ANOVA confirmed that the HD group demonstrated significantly greater self-perceived auditory processing difficulties than the control group ($F_{1,\ 35} = 62.3$; $p < 0.05$).

Control versus HD: Speech-in-Noise

Mean R-SPIN recognition performance (in % correct) for the control and HD groups as a function of SNR is shown in Figure 1. Recognition performance for high-predictability sentences is presented in the left panel and for low-predictability sentences in the right panel. As can be seen in Figure 1, recognition performance was poorer for the HD group than for the control group for both high- and low-predictability sentences at all SNRs. On average, the HD group performed 7.2% poorer (0 dB SNR) to 27.6% poorer (−12 dB SNR) for high-predictability sentences than the control group. Similarly, the HD group performed on average 22.9% poorer (0 dB SNR) to 26.8% poorer (−4 dB SNR) for low-predictability sentences than the control group. Recognition performance also differed as a function of context. Both control and HD groups exhibited better recognition performance for high-predictability sentences than for low-predictability sentences. Recognition performance for both control and HD groups varied as a function of SNR, with scores improving as SNR improved from −12 to 0 dB SNR for both high- and low-predictability sentences. Average scores improved 46.2% and 66.6% for the control and HD groups, respectively, for high-predictability sentences from −12 to 0 dB SNR. Similarly, average scores improved 50.4% and 49.9% for the control and HD groups, respectively, for low-predictability sentences from −12 to 0 dB SNR.

Table 3. Means and Standard Deviations (SD) for the HHIA and APQ

	HHIA		APQ	
	Unaided	Aided	Unaided	Aided
Control group Mean (SD)	0.1 (0.5)	—	24.5 (13.8)	—
HD group Mean (SD)	38.4 (20.1)	20.5 (15.9)	81.5 (26.9)	53.3 (21.6)

Notes: Data are presented for the control group and for the unaided and aided conditions for the HD group.

Before statistical analysis, the percentage R-SPIN data were transformed to rationalized arcsine units to address the error in variance associated with percentage data (Studebaker, 1985). A repeated measures ANOVA was used to evaluate the differences in R-SPIN recognition performance with group as the between-subject variable and context and SNR as within-subject variables. Results revealed a significant main effect of group ($F_{1,\ 35} = 91.8$; $p < 0.05$) confirming that the HD group demonstrated significantly poorer recognition performance than the control group for both high- and low-predictability sentences across all SNRs.

Results also revealed a significant main effect of context ($F_{1,\ 35} = 467$; $p < 0.05$) confirming that R-SPIN recognition performance was significantly better for high-predictability sentences than for low-predictability sentences. Posthoc paired sample *t*-tests with Bonferroni correction revealed significantly better R-SPIN recognition performance for high-predictability sentences than for low-predictability sentences across all SNRs for both control [-12 dB ($t_{19} = 8.1$; $p < 0.006$); -8 dB ($t_{19} = 6.7$; $p < 0.006$); -4 dB ($t_{19} = 9.3$; $p < 0.006$); 0 dB ($t_{19} = 14.2$; $p < 0.006$)] and HD groups [-12 dB ($t_{16} = 4.7$; $p < 0.006$); -8 dB ($t_{16} = 7.6$; $p < 0.006$); -4 dB ($t_{16} = 9.9$; $p < 0.006$); 0 dB ($t_{16} = 9.5$; $p < 0.006$)].

Similarly, results revealed a significant main effect of SNR ($F_{3,\ 105} = 209$; $p < 0.05$) with R-SPIN recognition performance improving from -12 to 0 dB SNR for both high- and low-predictability sentences. Posthoc paired sample *t*-tests with Bonferroni correction confirmed significant improvements in R-SPIN recognition performance with increasing SNR for high-predictability sentences for the control group [-12 versus -8 dB ($t_{19} = -6.6$; $p < 0.008$); -8 versus -4 dB ($t_{19} = -4.4$; $p < 0.008$); -4 versus 0 dB ($t_{19} = -5.9$; $p < 0.008$)]; for low-predictability sentences for the control group [-12 versus -8 dB ($t_{19} = -6.2$; $p < 0.008$); -8 versus -4 dB ($t_{19} = -6.5$; $p < 0.008$); -4 versus 0 dB ($t_{19} = -4.1$; $p < 0.008$)]; for high-predictability sentences for the HD group [-12 versus -8 dB ($t_{16} = -5.5$; $p < 0.008$); -8 versus -4 dB ($t_{16} = -5.6$; $p < 0.008$); -4 versus 0 dB ($t_{16} = -6.5$; $p < 0.008$)]; and for low-predictability sentences for the HD group [-12 versus -8 dB ($t_{16} = -4.8$; $p < 0.008$); -8 versus -4 dB ($t_{16} = -6.1$; $p < 0.008$); -4 versus 0 dB ($t_{16} = -4.3$; $p < 0.008$)].

Results revealed a significant interaction for context x SNR ($F_{3,\ 105} = 10.3$; $p < 0.05$). The significant interaction is a reflection of the differences in recognition performance between high-and low-predictability sentences. Recognition performance improved at a faster rate from -12 to 0 dB SNR for high-predictability sentences than for low-predictability sentences for both control and HD groups (see Figure 1).

Unaided versus Aided HD: Questionnaires

Mean HHIA and APQ scores and standard deviations for the HD group in the unaided and aided conditions are presented in Table 2. As seen in Table 2, mean HHIA scores for the unaided condition (38.4) were greater than the scores for the aided condition (20.5). A paired sample *t*-test confirmed that the HD group demonstrated significantly less hearing handicap when wearing hearing aids relative to the unaided condition ($t_{16} = 2.9$; $p < 0.05$). Similarly, mean APQ scores that were greater for the unaided condition (81.5) were

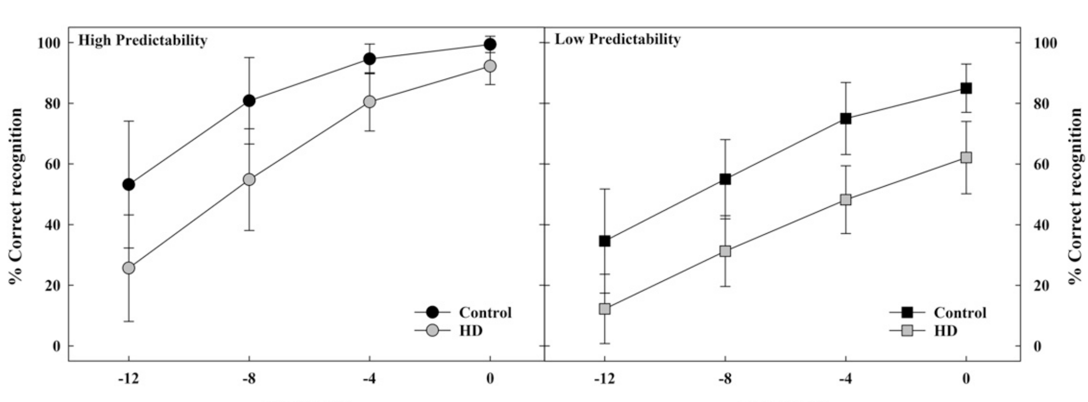

Figure 1. Mean R-SPIN recognition performance (in % correct) for the control and HD groups as a function of SNR in dB. Recognition performance for high-predictability sentences are presented in the left panel (circle symbols) and for low-predictability sentences in the right panel (square symbols). Error bars represent one standard deviation.

greater than the scores for the aided condition (53.5). A paired sample *t*-test confirmed that the HD group demonstrated significantly fewer self-perceived auditory processing difficulties when wearing hearing aids relative to the unaided condition ($t_{16} = 4.4$; $p < 0.05$).

Unaided versus Aided HD: Speech-in-Noise

Mean R-SPIN recognition performance as a function of SNR for the HD group comparing the unaided to aided condition is presented in Figure 2. Recognition performance for high-predictability sentences is presented in the left panel, and for low-predictability sentences in the right panel. As can been seen in Figure 2, R-SPIN recognition performance in the aided condition was superior to the unaided condition for both high- and low-predictability sentences at all SNRs. Using rationalized arcsine unit scores, a repeated measures ANOVA was used to evaluate the differences in R-SPIN recognition performance for the HD group with hearing aid condition, context, and SNR as within participants' variables. Results revealed a significant main effect of hearing aid condition ($F_{1, 16} = 79.1$; $p < 0.05$), confirming that recognition performance was significantly better in the aided versus unaided condition for high- and low-predictability sentences. Posthoc paired samples *t*-test with Bonferroni correction for high-predictability sentences revealed significantly better recognition performance in the aided condition for all SNRs: −12 dB SNR ($t_{16} = -5.7$; $p < 0.0125$), −8 dB SNR ($t_{16} = -5.6$; $p < 0.0125$), −4 dB SNR ($t_{16} = -4.3$; $p < 0.0125$), and 0 dB SNR ($t_{16} = -3.4$; $p < 0.0125$). Similarly, posthoc paired sample *t*-tests with Bonferroni correction for low-predictability sentences revealed better recognition performance in the aided condition for all SNRs: −12 dB SNR ($t_{16} = -7.1$; $p < 0.0125$), −8 dB SNR ($t_{16} = -6.8$; $p < 0.0125$), −4 dB SNR ($t_{16} = -7.9$; $p < 0.0125$), and 0 dB SNR ($t_{16} = -7.2$; $p < 0.0125$).

Results also revealed significant main effects of *context* ($F_{1, 16} = 418.8$; $p < 0.05$) and *SNR* ($F_{3, 48} = 109.9$; $p < 0.05$). Posthoc paired sample *t*-tests with Bonferroni correction were used to further evaluate the main effect of context in the aided condition. Results revealed significantly better recognition performance in the aided condition for high-predictability sentences than for low-predictability sentences at all SNRs: at −12 dB SNR ($t_{16} = 6.9$; $p < 0.0125$), −8 dB SNR ($t_{16} = 6.2$; $p < 0.0125$), −4 dB SNR ($t_{16} = 8.8$; $p < 0.0125$), and 0 dB SNR ($t_{16} = 7.9$; $p < 0.0125$). Posthoc paired sample *t*-tests with Bonferroni correction were also used to further evaluate the main effect of SNR in the aided condition. Results revealed significant differences ($p < 0.004$) in recognition performance between all SNRs for both high- and low-predictability sentences with the exception of the −4 versus 0 dB SNR high-predictability comparison ($t_{16} = -1.9$; $p > 0.004$) where mean recognition performance was near or at ceiling.

Significant two-way interactions were also found for context x SNR ($F_{3, 48} = 556.6$; $p < 0.05$) and SNR x hearing aid condition ($F_{3, 48} = 765.4$; $p < 0.05$). A three-way interaction was also found for context x SNR x hearing aid condition ($F_{3, 48} = 270.7$; $p < 0.05$). As can be seen in Figure 2, the significant interactions can be explained by better recognition performance for high-predictability sentences at the −4 and 0 dB SNRs in both the unaided and aided conditions.

Hearing Aid Use

The participants with HD recorded their hearing aid use time in a hearing aid diary. The categories of use were 0, 1–4, 4–8, and 8+ h. The number of hours of hearing aid use recorded by each participant per day was averaged across the four-week trial. The average number of hours of hearing aid use per participant is presented in Figure 3. As seen in Figure 3, nine

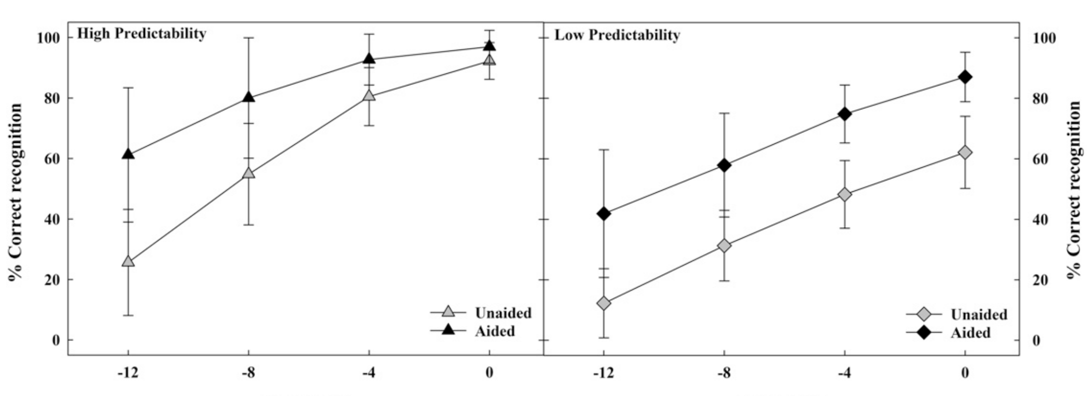

Figure 2. Mean R-SPIN recognition performance (in % correct) for the HD group as a function of hearing aid condition (unaided versus aided) and SNR in dB. Recognition performance for high-predictability sentences are presented in the left panel (triangle symbols) and for low-predictability sentences in the right panel (diamond symbols). Error bars represent one standard deviation.

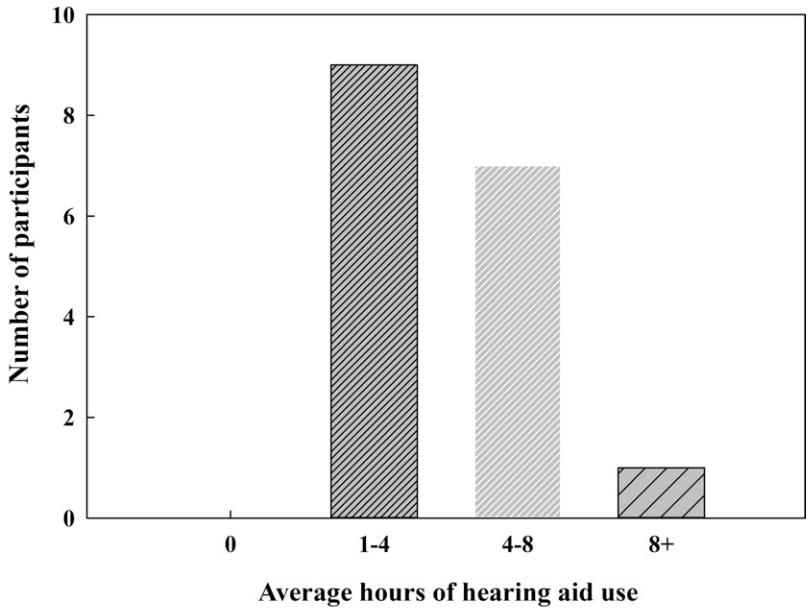

Figure 3. Number of participants reporting 0, 1–4, 4–8, and 8+ average hours of hearing aid use per day.

(53%) participants reported wearing the hearing aids on average 1–4 h per day, seven (41%) participants reported wearing the hearing aids on average 4–8 h per day, and one participant (6%) reported wearing their hearing aids on average 8+ h per day. Inspection of the individual hearing aid use data showed considerable variability in the number of hours reported by some participants. However, over the course the four-week trial, most participants wore the hearing aids at least 1–4 h per day.

The relationship between hearing aid use and initial (or unaided) hearing handicap (HHIA) and self-perceived auditory processing ability (APQ) was explored through Pearson's correlational analysis. Results revealed a strong positive and significant correlation ($r = 0.75$; $p < 0.05$) between the unaided HHIA score and the average number of hours of hearing aid use based on hearing aid use category (i.e., 1 = 0 h; 2 = 1–4 h; 3 = 4–8 h; 4 = 8+ h). This relationship is illustrated in Figure 4. HHIA scores are plotted on the abscissa as a function of the hearing aid use category on the ordinate. As seen in Figure 4, as the unaided HHIA score increased, so did the average number of hours of hearing aid use. In other words, participants having HD with greater hearing handicap wore their hearing aids on average for longer periods of time. The significant correlation between the initial HHIA score and hearing aid use, however, should be interpreted with caution. As can be seen in Figure 4, the majority of participants with HD had initial HHIA scores between 20 and 40, and only three participants with HD had HHIA scores greater than 40. When these three participants are removed from the analysis, the correlation between unaided HHIA scores and HA use is no longer significant. Results also revealed a weak, nonsignificant correlation ($r = 0.38$; $p = 0.13$) between the unaided APQ scores and the average number of hours of hearing aid use based on hearing aid use category.

Self-Reported Hearing Aid Benefit in Quiet and Noise

Participants were asked to record how helpful they found the hearing aids in both quiet and noisy listening environments. For each day of the trial, the participants recorded if they wore their hearing aids in quiet and/or noise. For each condition, the participants indicated if the hearing aids (a) helped a lot, (b) helped a little, (c) did not help, or (d) made listening worse. For listening in quiet, the majority (67%) of participants felt that the hearing aids either helped a lot or helped a little. Similarly for listening in noise, the majority (71%) of participants felt that the hearing aids either helped a lot or helped a little. At least one participant (#17) with minimal hearing handicap (unaided HHIA score of 24) did not perceive that the hearing aids were helpful in either quiet or noise, reporting that the hearing aids mostly did not help or to a lesser extent, made listening worse. In fact, participant #17 reported a 38-point increase on the HHIA and a 28-point increase on the APQ as a result of wearing the hearing aids.

DISCUSSION

The purpose of the present study was to investigate the benefits of a four-week trial with mild-gain, open-fit hearing aids utilizing adaptive multiband directional microphones and noise reduction for adults

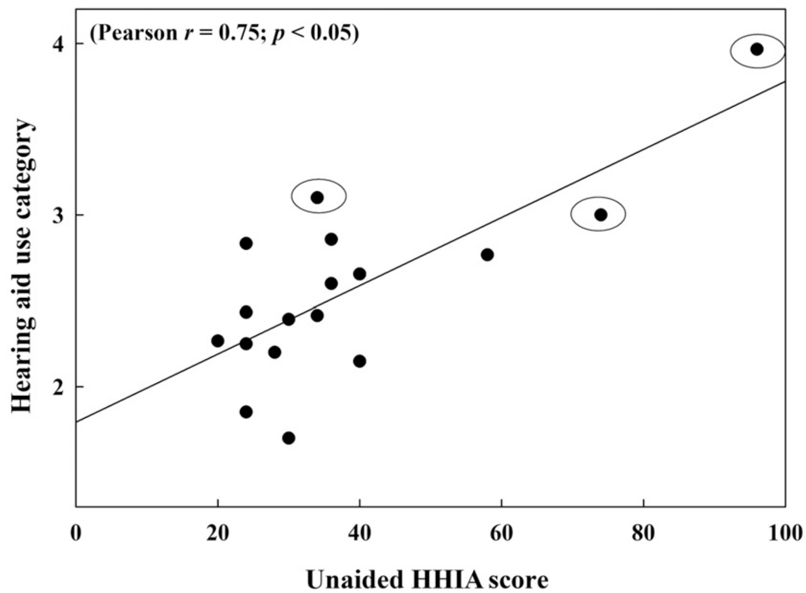

Figure 4. Individual data presented as a bivariate plot with the unaided HHIA scores on the abscissa and hours of hearing aid use category on the ordinate. Average hours of hearing aid use categories are defined as 1 = 0, 2 = 1–4, 3 = 4–8, and 4 = 8+ h. The line through the panel represents the linear regression. The three circled data points represent the participants who purchased the hearing aids after the trial.

with self-reported HD. Benefit was examined subjectively through questionnaires (i.e., HHIA and APQ) and objectively through a speech-in-noise test (i.e., R-SPIN). It was hypothesized that the HD group would perform significantly poorer than the control group on both subjective and objective measures. It was also hypothesized that the HD group would experience significantly reduced hearing handicap and self-perceived auditory processing difficulty, as well as significantly better speech recognition-in-noise performance in the aided condition when compared with the unaided condition.

Auditory Processing Test Battery

The present study recruited participants on the basis of self-reported HD as assessed by the HHIA (score of ≥20). Diagnosis of an APD was not required for participants with HD to participate in the study. Rather, the auditory processing test battery was used to characterize the HD group. Inspection of the auditory processing test results revealed that 16/17 (94%) participants with HD performed abnormally on at least one of the auditory processing tests administered (i.e., GIN, MLD, DDT, or SCAN-3:A). In addition, 17/17 (100%) participants with HD performed below the normal range for both high- and low-predictability R-SPIN sentences relative to the control group from the present study. One abnormal score does not constitute the diagnosis of APD for most published diagnostic criteria (Bellis and Ferre, 1999; ASHA, 2005; Katz, 2007; AAA, 2010). Such criteria often assess only objective measures of auditory processing for diagnosis of APD and require a minimum of two abnormal results from a battery of tests. The present study focused primarily on self-reported HD with objective measures providing supplementary information. The results of at least one abnormal test result for 94% of participants and two abnormal test results for 56% of participants on the auditory processing test battery, however, provide support for the self-reported HD of the experimental group. The fact that 100% of participants with HD performed below the normal range on both high- and low-predictability sentences of the R-SPIN also supports the self-reported complaints experienced by the HD group. Deficits in understanding speech in background noise (i.e., the R-SPIN) may be the cause of their self-reported HD.

Control versus HD: Questionnaire

HHIA and APQ scores were significantly higher for the HD group as compared with the control group, signifying that the individuals with self-reported HD experienced significantly greater self-perceived hearing handicap and auditory processing difficulties than the control group. Similar results were reported by Saunders and Haggard (1989). Saunders and Haggard investigated 20 individuals with OAD aged 16–55 yr and 40 control participants whom were matched on the basis of age, sex, socioeconomic status, and noise exposure. Hearing handicap was assessed with the Institute of Hearing Research Hearing Questionnaire. Participants with OAD, as a group, reported significantly greater self-perceived hearing handicap than the control group, particularly for comprehension of speech in noisy environments. Results of the present study and those of Saunders and Haggard provide quantifiable evidence that individuals with self-reported HD perceive their hearing ability differently than individuals without HD. In addition, data from the present study demonstrate the value of questionnaires as part of a diagnostic auditory processing test battery to help separate individuals with HD from typical "normal hearing" listeners.

Control versus HD: Speech-in-Noise

R-SPIN recognition performance revealed that the HD group performed significantly poorer than the control group as a function of both context (high- and low-predictability sentences) and SNR. Poorer recognition performance exhibited by the HD participants in comparison to the control group confirmed the results of the questionnaires (HHIA and APQ). Specifically, individuals who performed poorer on objective speech-in-noise measure (i.e., HD individuals) are the same individuals who reported greater hearing handicap (HHIA) and greater auditory processing difficulty (APQ). The poorer recognition performance and greater HHIA and APQ scores of the HD group in comparison to the control group demonstrate that individuals with HD come from a different subset of adults with normal peripheral hearing.

The effect of context (high versus low predictability) on recognition performance is clearly evident for both groups (see Figure 1). Both HD and control groups performed significantly poorer on low predictability relative to high-predictability sentences across all SNRs. For the HD group, the difference in recognition performance between high- and low-predictability sentences is particularly dramatic for the −4 and 0 dB SNR conditions (i.e., 33% poorer for low-predictability sentences). The consistent differences observed in recognition performance between high- and low-predictability sentences emphasize the importance of context, especially for HD individuals. Contextual cues engage top-down processing, allowing for the use of semantic and syntactic information (Wingfield, 1996), thereby aiding the listener in making inferences of what to expect next in a sentence. In addition, top-down processing allows the listener to use experience and linguistic knowledge to predict the meaning of a sentence. There is a clear relationship between context and speech recognition performance, with speech recognition performance improving as the amount of contextual information increases for both normal and hearing-impaired listeners (Duffy and Giolas, 1974; Wingfield, 1996). Similarly, a desirable SNR is ideal for speech recognition performance as listeners are able to use auditory cues (i.e., bottom-up processing) to a much greater extent than when the SNR is poor. Speech recognition performance is known to improve as the SNR increases for individuals with both normal and impaired hearing (Beattie, 1989; Beattie et al, 1997; Wilson et al, 2005; Wilson et al, 2012). In addition, poor SNR environments require the listener to use a greater amount of cognitive resources to attend to the message of interest than in a desirable SNR environment, leaving the listener with reduced cognitive resources for working memory and comprehension (Pichora-Fuller, 2003). The results of the present study are in agreement with the literature and suggest that context and SNR significantly impact individuals with HD as well. Communication strategies, often used with hearing-impaired listeners, typically focus on educating patients on important factors of communication such as context (e.g., making sure to know the topic of conversation) and SNR (e.g., turning the television off to have a conversation). Counseling regarding communication strategies may help improve the listening ability of individuals with HD.

Deficits in speech recognition-in-noise for HD participants relative to normal controls have been previously reported (Saunders and Haggard, 1989; Higson et al, 1994). Similar to the present study, Saunders and Haggard investigated speech-in-noise performance in a group with OAD using a Pseudo-Free-Field in Noise Test at a +5.5 dB SNR. The authors found that their OAD group performed significantly poorer on their speech-in-noise task than did a control group. Tremblay et al (2015) also investigated speech recognition-in-noise performance at a +8 dB SNR between HD and control groups using a word recognition in competing message test. In contrast to the results from the present study and those of Saunders and Haggard, Tremblay et al. found no significant difference in word recognition performance between the HD and control groups. It is likely that the +8 dB SNR prohibited Tremblay et al from observing differences between the HD and control groups. Both Saunders and Haggard and the present study employed more difficult SNRs where recognition performance for HD participants diverged from the normal controls. Auditory deficits of individuals who present with HD may go unnoticed if auditory tasks are too simple. Using auditory processing testing that challenges the auditory system will likely better reflect true auditory processing deficits.

Hearing Aid Trial: Questionnaires

HHIA and APQ scores were significantly reduced for the HD group after wearing the hearing aids for the four-week trial. Specifically, individuals with HD experienced significantly less self-perceived hearing handicap and auditory processing difficulties when wearing the hearing aids. In the only published hearing aid trial for individuals with HD (or APD), Kuk et al (2008) investigated subjective improvements in children with APD both pre- and postfitting of mild-gain, open-fit hearing aids. Subjective improvements were assessed through use of the CHAPS questionnaire which was completed by the children's parents and teachers. Kuk et al found improvements on the CHAPS in the aided condition, although the improvements were not significantly different from the CHAPS prehearing aid fitting. Although not directly comparable, the findings of the present study in addition to Kuk et al suggest that individuals with HD may experience reductions in hearing handicap and self-perceived auditory processing difficulties (e.g., subjective benefits) when using mild-gain, open-fit hearing aids with multiband directional microphones and noise reduction.

On average, the HD group reported a reduction in hearing handicap with amplification. It is important, however, to note that two HD participants (#12 and #17) experienced increased hearing handicap (i.e., greater HHIA scores) and one of the two (#17) also experienced increased self-perceived auditory processing difficulties (i.e., increased APQ score) after the hearing aid trial. As previously discussed in the results, participant #17 also reported that the hearing aids "did not help" or "made listening worse" in the hearing aid diary, supporting the questionnaire results. Although both participant #12 and participant #17 experienced improved R-SPIN recognition performance for both high- and low-predictability sentences with amplification, the questionnaire and hearing aid diary data clearly demonstrate that personal amplification outside the laboratory setting was not perceived to be beneficial. The experiences of participant #12 and especially that of participant #17 illustrate the importance of measures that assess self-perceived benefit when trialing amplification for listeners with HD and normal pure-tone thresholds.

Hearing Aid Trial: Speech-in-Noise

R-SPIN recognition performance revealed that, on average, HD participants performed significantly better with hearing aids than without for both high- and low-predictability sentences for all SNRs. Better recognition performance exhibited by the HD participants with versus without hearing aids demonstrates benefit from mild-gain amplification employing adaptive multiband directionality and noise reduction. For high-predictability sentences, the benefit of amplification is particularly evident at the most difficult SNRs (i.e., −12 and −8 dB SNR) where recognition performance improved on an average of 25–30%. When the SNR was more desirable (i.e., −4 and 0 dB SNR), little improvement from amplification was noted (2–9%), likely because performance was near ceiling both with and without the hearing aids. For recognition performance of low-predictability sentences, the benefit of amplification was distributed evenly across SNRs. At all SNRs, recognition performance improved at a relatively constant rate of 21–26%.

The results of unaided versus aided recognition performance from the present study are comparable to the results of Kuk et al (2008). Kuk et al found that children performed significantly better on NU-6 words in noise when using mild-gain, open-fit hearing aids as compared with no amplification. The results of the present study in addition to Kuk et al suggest that the use of mild-gain, open-fit hearing aids with adaptive multiband directionality and noise reduction may provide a feasible intervention for individuals with HD and speech-in-noise deficits.

Hearing Aid Use in Quiet and in Noise

Individuals with HD typically have complaints of difficulty understanding speech in background noise while speech understanding in quiet is often normal. For this reason, HD participants were asked to keep track of their impressions of hearing aid benefit when in quiet and in noise. HD participants reported that the hearing aids either "helped a lot" or "helped a little" the majority of the time (i.e., 67–71%) in both quiet and noisy environments. Further inspection of participant responses revealed that the hearing aids provided the greatest benefit (i.e., "helped a lot") more frequently for noisy environments than for quiet environments (25% versus 10%, respectively). The difference in benefit for quiet and noisy environments was less apparent for the "helped a little" category. The hearing aids "helped a little" more frequently in quiet environments (57%) than in noisy environments (46%). The hearing aids were found to provide no benefit (i.e., "did not help") only 27% and 20% of the time for quiet and noisy environments, respectively. The hearing aids negatively affected subjective listening (i.e., "made listening worse") only a small percentage of the time (7% and 10% for quiet and noisy environments, respectively). The subjective improvements found when wearing the hearing aids in noise and even in quiet are promising for the future utility of mild-gain amplification as an intervention for adults with self-reported HD.

HD Subjects Who Purchased the Hearing Aids after Trial

All HD participants were given the opportunity to purchase the hearing aids at a reduced cost at the conclusion of the four-week trial. Three of the 17 HD participants (#9, #14, and #18) purchased the hearing aids after trial, noting substantial self-perceived benefit from mild-gain amplification. Inspection of individual HD data demonstrated a clear pattern of objective (auditory processing test battery) and subjective (questionnaire) results for two of these three participants (#9 and #14). The auditory processing test battery data indicated performance below the normal range for at least two of the five measures, consistent with an APD diagnosis (re: AAA, 2010). Participant #9 exhibited abnormal performance on three out of five measures, and participant #14 exhibited abnormal performance on four out of five measures. Furthermore, inspection of the questionnaire data revealed that participants #9 and #14 exhibited the highest unaided HHIA and APQ scores, indicating the greatest degree of hearing handicap and self-perceived auditory processing difficulties of all the participants with HD. For participant #18, results were abnormal for one of five auditory processing measures, and her HHIA and APQ scores were near the mean for the HD group. All three participants experienced substantial reductions in questionnaire scores because of hearing aid use. Posttrial hearing handicap was reduced by 76, 42, and 30 HHIA points for participants #9, #14, and #18, respectively. Similarly, post-trial APQ scores were reduced by 56, 41, and 72 points for #9, #14, and #18, respectively. These three participants were also among those who reported wearing their hearing aids for longer time periods (4–8 h per day for participants #14 and #18, and 8+ h per day for participant #9).

The use of both questionnaire and auditory processing test battery data for individuals who present clinically with HD appears to be a good starting point for the consideration of treatment with mild-gain amplification. Based on the characteristics of the three participants who chose to pursue amplification after trial, however, the use of a ≥20 HHIA score as inclusion criteria was likely too liberal. In fact, participants with unaided HHIA scores below the group mean were less likely to find the hearing aids helpful. For individuals presenting clinically with self-reported HD and a normal pure-tone audiogram, an HHIA score ≥34 would be helpful when considering treatment with mild-gain amplification.

Conclusions

The current study is limited by a number of factors, including nonage-matched control participants, minimal investigation into participants' comorbid factors, use of only one intervention method, and lack of a sham condition. The control participants who participated in the study were not age-matched to participants with HD; therefore, age-related deficits could not be ruled out as a contributing factor to the present results. The likelihood that age played a significant role in the results of the present study, however, is mitigated by the fact that only four of the 17 participants with HD were significantly older than the control group. Mean R-SPIN recognition performance for the participants with HD divided by age (younger and older) is included in Appendix A. When comparing mean recognition performance at individual SNRs, minimal differences were present with the four older HD adults often performing better on average than the young HD adults. Further statistical analysis confirmed that R-SPIN recognition performance of the four older participants with HD did not significantly differ from the 13 younger participants with HD. (A repeated measures ANOVA comparing the four older participants with HD to the 13 younger participants with HD did not reveal significant difference in R-SPIN recognition performance [$F_{1,\ 15} = 1.5$; $p > 0.05$].) Future research should explore age as a confounding variable.

Previous research has identified comorbid factors that are associated with HD including anxious personality and history of otological symptoms (Saunders and Haggard, 1989), history of noise exposure (Kumar et al, 2012; Tremblay et al, 2015), depression (Higson et al, 1994; Tremblay et al, 2015), vision difficulties and neuropathy (Tremblay et al, 2015), lesions of the central auditory nervous system (Musiek et al, 2005), and a history of TBI (Gallun et al, 2012). The present study did not initially investigate comorbid factors; however, nine participants with HD were found to have a history of diagnosed or probable TBI. Future research should investigate additional comorbid factors (e.g., TBI, working memory, attention, depression, etc.) which may influence the listening and/or speech understanding of individuals with HD. For example, future studies could investigate the prevalence of HD in the TBI population, as individuals with TBI have been found to have high rates of measured auditory processing deficits (Musiek et al, 2004; Bergemalm and Lyxell, 2005; Fausti et al, 2009; Musiek et al, 2011). Additional testing outside the auditory domain may also be needed to assess comorbid factors such as attention. Conditions such as attention deficit disorder and attention deficit hyperactivity disorder have been thought, by some, to affect auditory processing testing (Lovett, 2011). Establishing a listener's attentional capabilities and their impact on HD may prove useful; however, more work in this area is needed.

Improvements in speech-in-noise performance found in the present study can be directly attributed to the use the mild-gain hearing aids that enhanced mid- to high-frequency speech sounds and improved the SNR because of the use of directional microphones. The hearing aid trial also resulted in an overall improvement in self-reported HD; however, the role of a placebo effect cannot be ruled out. The likelihood that a placebo effect contributed to the aided questionnaire results is moderated by the fact that self-perceived benefit from amplification was not universal. For most participants with HD, self-perceived benefit was noted primarily when listening in noisy environments when the adaptive directionality and noise reduction would have engaged, with less benefit noted in quiet conditions. Furthermore, two participants with HD failed to perceive benefit from the amplification in quiet or noise. Regardless, it would also be advisable that future research implement a sham condition in which participants are fit with mild-gain, open-fit hearing aids which only overcome insertion loss (i.e., provide no additional gain to listener) to fully assess a potential placebo effect. Future studies should also investigate various intervention strategies for the HD population. FM systems are used as interventions for children and adults with APD (Baran, 2002). Auditory rehabilitation/training can also be used for this population. A comparison of the various intervention methods (i.e., mild-gain hearing aids, FM systems, auditory rehabilitation/training, etc.) is needed to determine the differences in potential benefits of each.

Although a diagnosis of APD was not part of the inclusion criteria, the participants with HD in the present study had symptoms (e.g., difficulty understanding in background noise) consistent with APD. The HD groups' results on the auditory processing test battery and R-SPIN were also consistent with the performance of individuals with APD. Results of the present study suggest that individuals with HD consistent with APD do comprise a unique subset of adults with normal peripheral hearing. The significant differences found between HD and control participants suggest that individuals who present clinically with HD should be assessed beyond the standard audiometric test battery (i.e., pure-tones and speech understanding in quiet). It is higher level auditory processing tests which tax the auditory system and reveal the true auditory processing deficits of individuals with HD.

Results demonstrated that most participants with HD received significant benefit in hearing handicap and auditory processing abilities when wearing the mild-gain amplification. In addition, participants demonstrated significantly improved speech recognition performance on the R-SPIN with amplification. It is likely that participants from the control group would experience similar improvements in speech recognition-in-noise performance with the use of mild-gain amplification, particularly for the more difficult SNRs. The success of hearing aid use on a daily basis, however, would be mitigated by the lack of self-perceived hearing and auditory processing difficulties among control individuals. The present study suggests that mild-gain, open-fit hearing aids with adaptive multiband directional microphones and noise reduction may provide a viable treatment option for some individuals with HD consistent with APD. Clinicians should be aware that individuals with significant self-perceived hearing handicap and auditory processing difficulties (as assessed by questionnaires) in the presence of normal peripheral hearing may be candidates for audiological interventions including the use of mild-gain hearing aid technology.

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APPENDIX A

Table A1. Mean R-SPIN Recognition Performance (and Standard Deviations) in Percent Correct for Participants with HD Grouped as a Function of Age: Younger (≤35 years) and Older (≥48 years)

	Participants with HD	
R-SPIN	Younger (n = 13) (18–35 years)	Older (n = 4) (48–58 years)
High predictability		
12 dB SNR	22.5 (15.6)	34.0 (25.4)
8 dB SNR	52.9 (11.6)	64.0 (14.2)
4 dB SNR	80.6 (11.3)	84.0 (3.3)
0 dB SNR	92.9 (6.1)	92.0 (5.7)
Low predictability		
12 dB SNR	12.3 (11.6)	22.0 (17.4)
8 dB SNR	27.1 (8.2)	41.0 (15.1)
4 dB SNR	48.6 (12.3)	44.0 (14.4)
0 dB SNR	62.5 (10.9)	52.0 (14.2)

Notes: Data are presented for high- and low-predictability sentences as a function of SNR.