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Personal Amplification for School-Age Children with Auditory Processing Disorders

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Francis Kuk*
Amy Jackson†
Denise Keenan*
Chi-chuen Lau*

Abstract

Background: Children with auditory processing disorders (APD) are described to have a signal-to-noise ratio (SNR) difficulty. Frequency-modulated (FM) systems have been reported to improve this situation. Yet the use of personal amplification that may be more portable has not been attempted.

Purpose: To determine whether personal amplification would result in improvement in speech-in-noise performances (attentiveness and speech recognition) and daily functioning in children with diagnosed APD. In addition, the desired hearing aid features (such as required gain, directional microphone and noise reduction, and open-ear fitting) are examined.

Research Design: A single-blind, longitudinal descriptive study in which subjects served as their own control in various hearing aid conditions.

Study Sample: Fourteen normal hearing children who had a diagnosis of APD and who were between the ages of 7 and 11 participated.

Intervention: All subjects wore bilateral, mild-gain, behind-the-ear, wide dynamic range compression hearing aids fitted in an open-ear mode. Gain on the hearing aids was adjusted to provide approximately 10 dB of insertion gain for conversational input. Directional microphone and noise reduction were used on the hearing aids. Subjects wore the hearing aids home and were encouraged to use them as much as possible in their daily environments (school, home, and social activities). Subjects were seen four times: an initial visit where hearing aids were fitted, then visits at 2 weeks, 3 months, and 6 months after the initial fitting. The majority of the testing was completed during these final three visits.

Data Collection and Analysis: The children were evaluated on the Northwestern University word-list (NU–6) and the Auditory Continuous Performance Test (ACPT) in noise at most visits. The hearing aids were evaluated in the omnidirectional microphone mode only, omnidirectional microphone with noise reduction (NR) mode, and directional microphone with NR mode. The children's parents and teachers were asked to complete the Children's Auditory Processing Performance Scale (CHAPS) questionnaire both before and at the end of the study.

Results: The results showed that the use of hearing aids in the omnidirectional microphone mode alone did not improve speech identification in noise over the unaided condition. However, the inclusion of the NR algorithm and directional microphones improved speech understanding in noise. Amplification reduced the number of errors on the ACPT and improved several areas on the CHAPS; however, the results were not statistically significant.

Conclusions: The use of mild-gain, open-ear fitting hearing aids with a directional microphone and noise reduction algorithm may be attempted on some children with APD on a trial basis.

Key Words: Auditory processing disorder, directional microphone, hearing aids, noise reduction, open-ear fittings

Abbreviations: ACPT = Auditory Continuous Performance Test; ADHD = attention deficit hyperactive disorder; APD = auditory processing disorders; BTE = behind-the-ear hearing aid; CHAPS = Chil-

*Widex Hearing Aid Company, Office of Research in Clinical Amplification, Lisle, IL; †Hearing Alternatives, Inc., Tinley Park, IL

Francis Kuk, Ph.D., Widex Hearing Aid Company, USA, Office of Research in Clinical Amplification, 2300 Cabot Drive, Suite 415, Lisle, IL 60532; E-mail: fkuk@widexmail.com or fkuk@aol.com

dren's Auditory Processing Performance Scale; CS = competing sentences; DD = dichotic digits; DI = directivity index; FM = frequency modulation; FM + M = frequency modulation + microphone; FW = filtered words; LDL = loudness discomfort level; MPO = maximum power output; NR = noise reduction; NU–6 = Northwestern University word-list; PE = pressure-equalizing; PPS = pitch pattern sequence; PS = phonemic synthesis; REUR = real-ear unaided response; SNR = signal-to-noise ratio; SSW = staggered spondaic word; WDRC = wide dynamic range compression

Sumario

Antecedentes: Se describe que los niños con trastornos de procesamiento auditivo (APD) tienen dificultades con la tasa de señal-ruido (SNR). Se ha reportado que los sistemas de frecuencia modulada (FM) mejoran esta situación. Sin embargo, el uso de una amplificación personal que pueda ser más portátil no se ha intentado aún.

Propósito: Determinar si la amplificación personal produciría una mejoría en el desempeño en el lenguaje en medio de ruido (atención y reconocimiento del lenguaje) y en el funcionamiento diario de niños con diagnóstico de APD. Además, se examinan los rasgos deseados en un auxiliar auditivo (ganancia requerida, micrófono direccional, reducción del ruido y adaptaciones de oído abierto).

Diseño de Investigación: Estudio descriptivo, longitudinal, de ciego sencillo, en el que los sujetos sirvieron como sus propios controles en varias condiciones de su auxiliar auditivo.

Muestra del Estudio: Participaron catorce niños con audición normal que tenían un diagnóstico de APD y edades entre 7 y 11 años.

Intervención: Todos los sujetos utilizaron auxiliares auditivos retroauriculares, bilaterales, de ganancia leve, con compresión de rango dinámico amplio, y en modo de oído abierto. La ganancia de los auxiliares se ajustó para brindar aproximadamente 10 db de ganancia de inserción para ingreso de conversación. Se usó micrófono direccional y reducción de ruido en dichos auxiliares. Los sujetos llevaron los auxiliares auditivos a sus casas y se le instó a usarlos tanto como fuera posible en sus ambientes cotidianos (escuela, hogar y actividades sociales). Los sujetos fueron revisados cuatro veces: una visita inicial donde se adaptaron los auxiliares auditivos, luego visitas a las 2 semanas, a los 3 meses y a los 6 meses después de la adaptación inicial. La mayoría de las pruebas se completaron durante estas últimas tres visitas.

Recolección y Análisis de los Datos: Los niños fueron evaluados con la lista de palabras de la Universidad Northwestern (NU-6) y con la Prueba de Desempeño Auditivo Continuo (ACPT) en ruido, en la mayoría de las visitas. Los auxiliares auditivos fueron evaluados con el modo de micrófono omnidireccional solo, en el modo de micrófono omnidireccional con reducción de ruido (NR) y en el modo de micrófono direccional con NR. Se les pidió a los padres y maestros de los niños que completaran el cuestionario de la Escala Infantil de Desempeño en Procesamiento Auditivo (CHAPS), tanto antes como al final del estudio.

Resultados: Los resultados mostraron que el uso de auxiliares auditivos en el modo de micrófono omnidireccional solo, no mejoraban la discriminación del lenguaje en ruido sobre la condición no amplificada. Sin embargo, la inclusión del algoritmo NR y los micrófonos direccionales mejoraron el entendimiento del lenguaje en ruido. La amplificación redujo el número de errores con el ACPT y mejoró varias áreas en el CHAPS; sin embargo, los resultados no fueron estadísticamente significativos.

Conclusiones: El uso de auxiliares auditivos de ganancia leve y adaptación a oído abierto con micrófono direccional y algoritmo de reducción de ruido puede intentarse en algunos niños con APD en forma de prueba.

Palabras Clave: Trastorno de procesamiento auditivo, micrófono direccional, auxiliares auditivos, reducción de ruido, adaptación de oído abierto

Abreviaturas: ACPT = Prueba de Desempeño Auditivo Continuo; ADHD = trastornos de déficit de atención con hiperactividad; APD = trastornos de procesamiento auditivo; BTE = auxiliar auditivo retroauricular; CHAPS = Escala Infantil de Desempeño en Procesamiento Auditivo; CS = Frases de competencia; DD = dígitos dicóticos; DI = Índice de directividad; FM = modulación de la frecuencia; FM + M = modulación de la frecuencia + micrófono; FW = palabras filtradas; LDL = nivel de molestia por sonoridad; MPO = máximo poder de salida; NR = reducción de ruido; NU-6 = Lista de palabras de la Universidad Northwestern; PE = ecualización de la presión; PPS = secuencia de patrón de tonos; PS = síntesis fonémica; REUR = respuesta no amplificada de oído real; SNR = tasa señal-ruido; SSW = palabras espondaicas escalonadas; WDRC = compresión de rango dinámico amplio

INTRODUCTION

Auditory processing disorder (APD) is a diagnosis given to children whose hearing sensitivity is typically normal (Jerger and Musiek, 2000) but who exhibit behavioral symptoms such as difficulty understanding in noise, easy distractibility, easy irritation by loud or sudden noises, difficulty following directions, difficulty in expressive and receptive language, difficulty localizing sounds, disorganization, and forgetfulness. Many children with such a diagnosis also experience social problems that indirectly result from poor language and academic skills (Baran, 1998). Often children with APD have coexisting disorders such as attention deficit hyperactivity disorder (ADHD; Chermak et al, 2002). These coexisting disorders make the diagnosis of APD difficult and controversial.

Intervention strategies to help children with APD fall into three main categories. The first is a bottom-up approach focused on training and on increasing the children's auditory perceptual skills (Chermak and Musiek, 2002). An example may be training on auditory closure where the child is trained to fill in missing words. The second approach is a top-down approach targeted at enhancing the children's language and cognitive resources (Chermak and Musiek, 1997). An example may be vocabulary-building exercises. The third and final approach focuses on improving the quality of the auditory signals or environmental modifications (Bellis, 2002). An example may be the use of a sound–field amplification system in the classroom or the use of individual frequency modulation (FM) devices. We offer the use of personal hearing aids as another approach in this category. The evaluation of such a possibility—that is, the use of personal hearing aids—is the focus of the present study.

One of the major difficulties for children with APD is that they are easily distracted in noisy backgrounds (Sloan, 1998). They need listening environments that have a favorable signal-to-noise ratio (SNR). In this regard, strategies that improve the SNR of listening environments have been proposed. One recommendation is the use of personal FM devices in the classroom (Rosenberg, 2002). Simply put, these devices modulate the teachers' voices that are picked up by a microphone placed close to the teachers' mouths and then transmit the modulated voices with a high-frequency carrier so that they are not audible to normal ears. The transmitted voice is subsequently demodulated by an FM receiver so the listener hears the voice through headphones or ear-level hearing aids (for those who have a hearing loss). The advantage of an FM system is that the effect of distance, interfering noise, and reverberation in the classroom is overcome. This approach will give the children a favorable level of the teacher's voice (signal) over the noise level of the classroom (reverberation and interference).

FM systems have been used primarily for children with a hearing loss. Hawkins (1984) studied the speech recognition ability of nine hearing-impaired children in a classroom under various hearing aid configurations (monaural, binaural, omnidirectional, and fixed directional), FM coupling methods (direct input, loop, inductor, silhouette, and environmental microphone on and off), and input SNR. The author reported that the various FM coupling methods yielded about 15 dB of SNR improvement in the FM alone condition. However, in the FM plus microphone (FM + M) condition, most of the SNR advantage offered by the FM disappeared because of the mixing of the FM transmitted signals and the directly amplified signals. The author suggested that FM units should be used in the FM alone position to retain their SNR advantage.

Other than anecdotal comments, there have been virtually no published reports on the use of FM on normal hearing children with APD. Recently, Updike (2005) reported on the use of a commercial FM system on 12 children who were 8–12 years old and had been diagnosed with APD and ADHD (6 in each group). The FM receiver resembled a behind-the-ear hearing aid (BTE) that was worn in an open-ear manner. The output of the FM receiver could be adjusted by the wearer through a volume control on the receiver. The author reported improved word recognition in quiet and in noise (+5 dB SNR) for both groups of subjects. In addition, classroom behaviors and academic performance were also improved.

Despite Updike's (2005) encouraging results, there are practical issues limiting FM use for children with APD. By the FM system's very design, the success of the system is highly dependent (a) on the willingness of the wearer to hand the FM microphone to the speakers and (b) on the participation of the speakers. As a result, the use of the FM in real-life situations will likely be limited for many children and thus may not ensure an optimal SNR in their real-life environments. To be acceptable, an approach that ensures a favorable SNR, allows portability, and does not depend on speaker participation is necessary. In this regard, the use of personal hearing aids may be an option if they enhance the child's performance in noise. In addition to the advantage of portability, a smaller device such as the personal hearing aid may provide motivation for normal hearing children with APD to accept and wear the device.

Considerations in Personal Amplification

There are special hardware requirements and fitting considerations in a hearing aid when it comes to fitting those aids to a normal hearing child with APD. Some of the general considerations in pediatric fittings were discussed in Kuk and Marcoux (2002).

1. *Multichannel processing*. With today's hearing aids, differential amplification may be applied so that the overall amplified sounds are optimized for speech intelligibility. A multichannel hearing aid has the best potential for providing appropriate differential amplification. This amplification may improve speech intelligibility in quiet and in noise over the nonamplified situation.

2. *Wide dynamic range compression (WDRC)*. The optimal amount of gain on the hearing aid would likely change with the input level. One may argue that—for a low input level sound—one needs to have higher gain in order to provide greater audibility of the background sounds. As the input level increases, gain should decrease so the output of the hearing aid is not much higher than the input—that is, "0" gain or even negative gain. Decreasing gain may also limit the distractibility of the higher input sounds. A hearing aid that uses WDRC instead of linear processing should be a requirement for these children.

3. *Mild gain with maximum power output (MPO) adjustment*. The amount of amplification that is considered optimal for people with "normal" hearing needs deliberation. Typically, hearing aids are fit based on the amount of hearing loss of the wearers. In the case of individuals with APD only, their normal hearing sensitivity means that minimal to no amplification is needed. Adding amplification would improve neither the audibility of sounds nor the SNR of the amplified sounds. From that perspective, some gain or amplification is necessary. But if gain is prescribed, the amplified sounds could be a potential source for increased distractibility and overamplification if they are not properly controlled and monitored. If one is to minimize the risk of overamplification, the hearing aid must use mild gain. It must also have an MPO control so it may be adjusted to a level that is below the loudness discomfort level (LDL) of a normal hearing child but high enough to preserve the temporal integrity of the output.

To achieve the objective of increased audibility for soft sounds without increasing the risk of overamplification, we will evaluate whether providing 10–15 dB gain for very soft sounds, 5–10 dB for conversational sounds, and close to 0 dB gain for very loud sounds would be acceptable. This amplification would result in soft sounds being more noticeable and comfortably audible, conversational sounds being louder but still comfortably loud, and loud sounds being transmitted at their unprocessed level. As a reference, the natural resonance that is provided by one putting his or her hand behind the pinna is approximately 10–12 dB in the 1000–2000 Hz region. Nonetheless, the appropriateness of this gain target of 10–15 dB needs validation.

4. *Directional microphones*. Advances in technology have made available the processing algorithms that enhance speech understanding in noise. One such area is directional microphone technology. These microphones are designed to maintain their sensitivity to sounds that originate in front of the wearer and to reduce their sensitivity to sounds that originate from the sides and back of the wearer (Valente, 1999). Valente and Mispagel (2004) tested the efficacy of a fully adaptive directional microphone on adult hearing-impaired subjects with speech in the front and speech-shaped noise at two noise configurations: at 180° and at 90°, 180°, and 270°. The results showed that this technology improved the SNR by 4–6 dB, depending on the configuration of the noise source and the degree of hearing loss of the wearers.

It is assumed that children would show the same order of SNR improvement as adults. Kuk et al (1999) demonstrated that school-age children with bilaterally symmetrical mild to severe hearing loss showed almost 20% improvement in speech recognition scores in noise at a −7 dB SNR with the speech-shaped noise directly in the back. Gravel et al (1999) used a similar test setup and reported similar findings in children. The authors are not aware of any studies reporting the use of this technology in children with APD.

5. *Noise reduction (NR)*. Another hearing aid feature that has been marketed to improve SNR is the use of NR algorithms. These algorithms have two components. The first component identifies the nature of the input—for example, "speech" versus "noise." The second component reduces gain in the channels where noise is identified. The amount and rate of gain reduction vary by manufacturers. In addition, the level of activation and the relative importance placed at different frequencies also vary (Chung, 2004).

NR algorithms have not been shown to improve the SNR of the listening situations; rather, they have been shown to improve the listening comfort in the adult wearers (Ricketts and Hornsby, 2005). One theoretical concern that was raised in regards to the use of NR algorithms in the pediatric population is the potential loss of speech cues from gain reduction. Fortunately, no published studies have shown any negative consequences of using this feature.

Because of the associated gain reduction, an advantage of an NR algorithm is its potential to further minimize the risk of overamplification in noise and to improve listening comfort. In the case of children with APD, one may speculate that an improvement in listening comfort could lead to an improved tolerance (and acceptance) in noise and perhaps an improved speech understanding in noise. This possibility will be explored in this study.

6. *Open-fitting*. Anyone may reject amplification if it is not comfortable, even when it is beneficial. One aspect of comfort is the physical occlusion of the ear when hearing aids are worn. There can be two consequences. One is the physical discomfort in the child's ears. The other is the perception of "hollowness" of the child's voice when he or she speaks with the hearing aids in situ. This perception is the well-known occlusion effect, and it has been one of the main reasons for hearing aid dissatisfaction in adult hearing aid wearers (Kuk and Ludvigsen, 2002).

In recent years, open-ear hearing aids have been reintroduced to increase wearer comfort and to eliminate the occlusion effect. These are typically miniature BTEs that are connected to different-sized stock ear-tips through a plastic tubing that is thin (typically less than 0.8 mm inner diameter) and flexible. The openness of the fitting improves the comfort of the fit and eliminates the occlusion effect, while the thin tube increases the cosmetic acceptance of this type of fitting. Furthermore, the openness of the ear canal maintains its natural resonance.

Open-ear fittings have limitations. First, because of the openness of the fitting, the maximum available gain before feedback may be limited. Dillon (2001) has shown that a tube fitting limited the available gain at 3000 Hz to only 26 dB in a BTE that does not have active feedback cancellation. Second, a thin-tube fitting limits the bandwidth of the amplification to restrict the amount of high-frequency output. Third, the openness of the fitting decreases the directivity index (DI) of the directional microphone in low- to middle-level frequencies (Dillon). This decrease reduces the effectiveness of the directional microphone and limits its potential for SNR improvement. Despite the reduced DI, an open-ear directional microphone retains some of its directivity, yielding a 1–2 dB SNR improvement over an omnidirectional microphone in adults (Kuk et al, 2005).

Although the issues with limited available gain and high-frequency bandwidth are reasons to be cautious with open-ear fittings in children, they may be of less importance when children with APD are considered. First, normal hearing children with APD may not require a large amount of gain from hearing aids. The 10–15 dB gain for soft sounds is clearly within the "safe" region of amplification, where no feedback would occur even without any active feedback cancellation mechanism in the hearing aid. This speculation may be further examined in this study. Second, despite the limited high-frequency bandwidth/gain of the hearing aid, there is no indication that children with APD would require extra gain from the hearing aid in the high frequencies that cannot be achieved by an adjustment of the available gain parameters.

These considerations suggest that if personal amplification is to be recommended to children with APD, a BTE that uses a thin-tube, open-ear fitting would have the highest likelihood of being acceptable. A smaller BTE (rather than a standard size) may be more acceptable because of its cosmetic appeal. Furthermore, the use of hearing aids that have flexible multiple channels using WDRC processing, directional microphones, and NR algorithms may be necessary to improve the SNR of the listening environment. Thus, this study was initiated to evaluate whether personal hearing aids selected with such considerations would improve the speech understanding in noise and communication abilities of children with APD. In addition, the acceptability of and acclimatization to personal hearing aids were evaluated.

METHOD

Participants

Participants were recruited from one of the second author's patient databases about patients who carried a diagnosis of APD. Children who matched the age, and diagnosis criteria were recruited. The diagnosis was based on the criteria recommended by the Technical Report on (Central) Auditory Processing Disorders published by the American Speech-Language-Hearing Association (ASHA, 2005). Specifically, such a diagnosis required the child's performance on two or more tests in a battery of tests to be two standard deviations below the mean. During this study, the core test battery used by the second author included the Staggered Spondaic Words (SSW), Phonemic Synthesis (PS), Filtered Words (FW), Dichotic Digits (DD), Competing Sentences (CS), Pitch Pattern Sequence (PPS), and Speech in Noise tests. These tests were available on a compact disc distributed by Auditec of St. Louis; they were conducted under insert earphones at 50 dB SL (re: SRT) in a sound booth.

The parents of the potential participants were contacted by telephone and were given a brief description of the study, including its purpose, its requirements, and any potential risks. Both the parents and students who consented to participate signed a written consent that summarized the study's purpose and potential risks. The children's teachers and/or other professionals (such as social workers, psychologists, or speech pathologists) were contacted through letters so they might evaluate the performance of the participants on the Children's Auditory Processing Performance Scale (CHAPS) before and after the participants wore the study hearing aids. Medical clearance from the child's primary physician was also obtained before the hearing aid fitting. The participants were not compensated for their participation in the study; however, they were given the option

Table 1. Summary Information of All Participants

Subject	Age/years	Gender	ADHD	Tests Administered	Tests Failed	Judged Auditory Processing Deficit
2	9	F		SSW, PS, FS, DD, S/N, PPS, CS	SSW, PS, DD, PPS	Binaural integration, auditory synthesis, temporal patterning
3	8	M		SSW, PS, FS, S/N, PPS	SSW, PS, PPS	Binaural integration, temporal patterning, auditory synthesis
4	8	M		SSW, PS, FS, S/N	SSW, PS, S/N	Binaural integration, auditory synthesis, auditory closure
5	11	M	yes	SSW, PS, FS, S/N, TCS, DD, DPS	PS, FS, TCS, DPS	Auditory closure, auditory synthesis, temporal patterning
6	10	M	yes	SSW, PS, FS, S/N, TCS, DD, DPS	PS, FS, TCS, DPS	Auditory closure, auditory synthesis, temporal patterning
7	9	F		SSW, PS, S/N	SSW, S/N	Binaural integration, auditory closure
8	10	M		SSW, PS, S/N, FS, DD, BF	SSW, PS, S/N, BF	Binaural integration, auditory synthesis, binaural interaction, auditory closure
9	11	M		SSW, PS, S/N, FS, DD	SSW, PS, FS, DD	Binaural integration, auditory closure, auditory synthesis
10	7	F		SSW, PS, S/N	SSW, PS	Binaural integration, auditory synthesis
11	7	F	yes	SSW, PS, DD, S/N, FS, TCS, BF, CS, PPS	SSW, PS, TCS, S/N, FS	Binaural integration, temporal patterning, auditory synthesis, auditory closure
12	10	M	yes	SSW, PS, S/N	SSW, PS	Binaural integration, auditory synthesis
14	7	M		SSW, PS, S/N, DD, FS, RGDT, PPS, TCS	SSW, PS, FS, DD, PPS	Binaural integration, auditory synthesis temporal patterning, auditory closure
15	8	F		SSW, PS, S/N, FS	SSW, PS, FS	Binaural integration, auditory closure, auditory synthesis
17	10	F		SSW, PS, S/N, DD	SSW, PS	Binaural integration, auditory synthesis

Note: BF = binaural fusion, CS = competing sentence, DD = dichotic digit, DPS = duration pattern sequence, FS = filtered word/filtered speech, PPS = pitch pattern sequence, PS = phoneme synthesis, RGDT = Random Gap Detection Test, S/N = speech in noise, SSW = staggered spondee word, TCS = time compressed sentences.

to purchase the study hearing aids at a discount at the end of the study if they desired.

A total of 17 participants (10 boys and 7 girls) were recruited into the study, each for a period of 6 months during the last two quarters of the school year (from December 2005 to June 2006). Five participants had also been diagnosed with ADHD by their physicians, while the others were diagnosed with APD alone. These participants were included because of the difficulty in separating the two conditions. All the participants had been diagnosed with APD/ADHD for at least 9 months before the start of the study. Other than participant #5, all the children with ADHD were on medication while completing the APD tests. The average age of the participants was 9.0 years (SD = 1.4 years), with a range from 7 to 11 years. All the participants had normal intelligence and were receiving speech and language therapy at the time of the study. One was also using an FM in the classroom. Three participants (#1, #13, and #16) withdrew from the study because of anxiety from wearing the hearing aids and from peer pressure. The tests that were administered, the tests that the children failed, and the processing deficits judged by the second author on each individual participant are reported in Table 1.

The hearing sensitivity of the participants at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz was measured at the initial fitting and at the end of the study. All had normal hearing (less than 10 dB HL at any frequency), and none of the participants showed more than 5 dB variation in hearing thresholds between prefitting and postfitting. In addition, impedance audiometry (including tympanogram and acoustic reflex) was also performed on all but two of the children (they had PE [pressure-equalizing] tubes) at each visit to monitor the status of the middle ear. Frequent breaks (that is, two or three) were provided during each test session in order to keep the participants on task. Each session was typically less than an hour to keep the children as attentive as possible.

Hearing Aids

All participants were fitted with bilateral Widex Vita élan (SV-9e) hearing aids. This device is a three-channel, slow-acting WDRC hearing aid coupled to a thin-tube stock ear-tip. Open-ear fitting was chosen to ensure maximal comfort and minimal occlusion. The hearing aid also has a switchable directional microphone that allows a choice between an omnidirectional microphone and a fixed two-port, directional microphone that uses a hypercardioid polar pattern.

This hearing aid also has an NR algorithm. This algorithm uses a patented level-distribution analysis to differentiate between "speech" and "noise" input in each of its three channels (Kuk et al, 2002). Gain settings on the hearing aid are maintained when a "speech" signal is estimated. A "noise" estimate will lead to gain reduction in the appropriate channel. So the aid can preserve intelligibility, gain reduction occurs only when the input level is at or above a conversational level. The amount of gain reduction increases as the input level increases or when the SNR becomes poorer. In addition, differential gain reduction is used so that frequency channels that are less important to speech intelligibility receive more gain reduction than channels that are more important for speech intelligibility. These steps are taken to preserve intelligibility while improving listening comfort. This algorithm may be activated or deactivated by the clinician, and different amounts of gain reduction (0, 6, 12, and 18 dB) may be applied.

This hearing aid also has two memories (or programs) where two sets of electroacoustic settings may be stored and accessed through a push-button on the hearing aid. Both programs were used in this study for real-world evaluation, and both programs used the same electroacoustic frequency-gain responses. They differed in the use of the directional microphone and NR. In program 1 (or quiet program), an omnidirectional microphone was used without any NR. In program 2 (or noise program), the fixed directional microphone was activated along with the NR algorithm at a maximum default gain reduction of 12 dB. During the 6-month study, participants were instructed to try the preset programs (selectable button) at school and at home and to choose the preferred program. They were not informed of the nature of these two programs or the differences between them, although the first program was always the quiet program and the second the noise program.

Fitting of the Hearing Aids

The proper earset (thin tube with appropriate size eartip) was first selected for each participant. Because of the normalcy of the participants' hearing sensitivity, the typical recommendation of measuring the in situ thresholds (or sensogram) associated with this hearing aid was not followed. Rather, the audiogram threshold at 500 Hz was entered as the in situ threshold (sensogram), and the sensogram at 1000, 2000, and 4000 Hz was set to 40 dB HL for every participant. Afterwards, a feedback test was performed to estimate the feedback path associated with the fitting and to minimize any potential risk of feedback. Figure 1 shows the real-ear, frequency-output response of the hearing aid to a 50 dB and a 65 dB SPL speech-shaped composite signal (Frye 6500). Comparing this output to the real-ear unaided response (REUR) at the 50 dB SPL input level, one can conclude that minimal insertion gain was provided to frequencies below 500 Hz and above 3000 Hz (from the REUR). However, about 15 dB of real-ear insertion gain was provided to sounds between 700 and 2000 Hz for a soft (50 dB SPL) input. About 10 dB of gain was provided to a 60 dB input for the same frequency range. The real-ear OSPL90 output of the hearing aid was below 100 dB SPL for all frequencies except those between 2000 and 3000 Hz. The hearing aids were programmed using Compass v3.5.

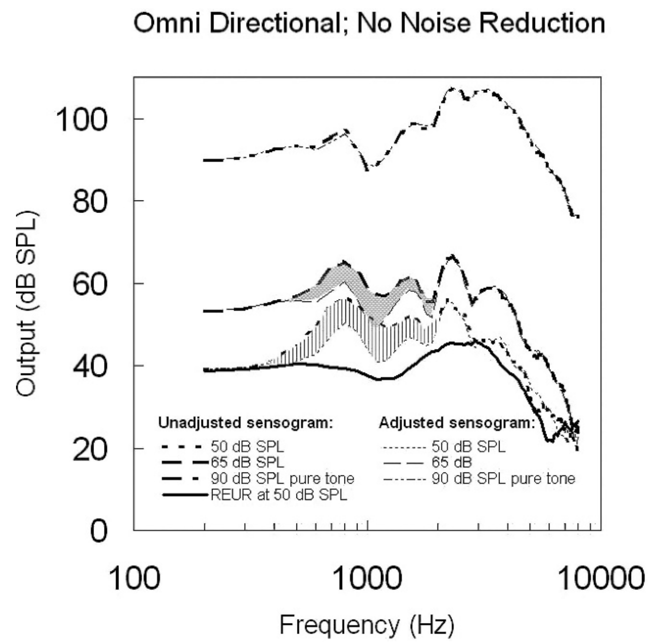

Figure 1. Real-ear output of the hearing aid to a 50 and 65 dB SPL speech-shaped composite noise input. The OSPL90 curves and the real-ear unaided response (REUR) at a 50 dB SPL input level are also shown.

The initial sensogram values at 1000 Hz were decreased to 30–35 dB HL in 6 participants (#2, #5, #6, #10, #11, and #12) because they indicated that the amplified sounds were too loud. The shaded areas in Figure 1 show the result of lowering the sensogram. Gain was reduced by about 6 dB at the 50 dB SPL input and by 4 dB at the 60 dB SPL input. This change yielded a real-ear gain of about 10 dB across frequencies from 800 Hz to 2000 Hz. All the participants indicated that the final assigned gain was appropriate in all subsequent visits. No complaints of loudness discomfort, poor sound quality, or "strangeness in own voice" were reported.

Evaluation Materials

Speech Recognition in Quiet and in Noise

All testing was conducted in a sound booth (Acoustic Systems RE 413). Speech recognition in quiet was assessed using the recorded NU–6 word-list delivered through a GSI-61 audiometer and presented through a loudspeaker placed 1 m in front of the participant (0° azimuth) at a fixed level of 68 dB SPL.

The speech-shaped noise on the audiometer was used as the competition during noise testing. It was presented through a loudspeaker placed at 180° azimuth. For NU–6 testing, the noise level was individually adjusted so that the word-recognition score in noise during the initial evaluation was between 20% and 60%. This adjustment was made to estimate a sensitive noise presentation level where the ceiling and floor effects may be avoided so the effects of signal processing can be apparent. For the adjustments to achieve that goal, the noise level was initially set at 68 dB SPL (and speech at the same level), and the word score was determined. The noise level was adjusted in 5 dB steps when the word scores exceeded the criterion range. The final SNR that yielded a performance between the 20% and 60% range was used at all subsequent visits when testing speech in noise performance on the NU–6. This noise-level adjustment corresponded to an SNR level of −10 dB (noise at 78 dB SPL) for three participants (#2, #7, and #8), −5 dB (noise at 73 dB SPL) for nine participants (#3, #4, #5, #6, #9, #10, #11, #12, and #14), and 0 dB (noise at 68 dB SPL) for two participants (#15 and #17).

Auditory Continuous Performance Test (ACPT)

The ability to sustain auditory attention was assessed using the Auditory Continuous Performance Test (ACPT; Keith, 2000) with the speech materials presented in front and the competition in the back (180°). During this test, participants listened to a list of words and raised their thumb every time they heard the target one-syllable word. In this case, the target word was "dog." In the present study, 96 words were delivered six times each. The test was scored by counting the number of target words that were missed (errors of inattention or omission) and the number of responses given when the target word was not presented (errors of impulsivity or commission). Speech was presented at 46 dB HL and noise at 53 dB HL. The test took approximately 12–15 minutes to complete.

Children's Auditory Processing Performance Scale (CHAPS)

The CHAPS (Smoski et al, 1998) is designed to quantify the observed listening behaviors of children age 7 years and older. It is used as a screening test to identify children who are at risk for auditory processing disorders. It has 36 questions that are grouped into six listening categories. They include "Noise" (i.e., in a room where there is background noise), "Quiet" (i.e., in a quiet room while others may be present), "Ideal Situation" (i.e., in a quiet room without distraction and with good eye contact), "Multiple Inputs" (i.e., other modes of input such as visual, tactile, etc., are available in addition to auditory), "Auditory Memory Sequencing" (i.e., being required to recall spoken information), and "Auditory Attention Span" (i.e., extended periods of listening). The number of questions in each listening category varies (3 questions each in "Ideal" and "Multiple Inputs," 7 questions each in "Noise" and "Quiet," and 8 questions each in "Auditory Memory Sequencing" and "Auditory Attention Span").

The response to each question may range from −5 (cannot function at all) to +1 (less difficulty). The performance of the participant in each listening category is compared to the difficulty reported by children of similar age and background. An average score lower than −1.0 in any listening category is at risk for that category. According to the authors, 45% of students in the at-risk range required no special support services, while 55% required special support to achieve success in school. In addition, 50% of those at risk had below grade-level reading ability. The CHAPS was completed once at the beginning of the study and once at the end of the study by the children's parents and teachers.

In addition to the standardized questionnaires, five questions were asked of each participant at the end of the study to assess their overall impression of the amplification system. They were as follows: "Do you wear your aids at school/home?" "Do you like to wear your aids, or does your mom make you?" "When you wore your aids, did you hear your teacher 'the same,' 'a little better,' or 'a lot better'?" "When you wore your hearing aids, did you hear your mom or dad 'the same,' 'a little better,' or 'a lot better'?" "Do you wear your hearing aid on program 1 or 2?" Open-ended subjective comments from the teachers and the parents were also solicited.

Procedures

Four visits were scheduled for each participant. The participants' teachers and parents were asked to complete the CHAPS questionnaire before their first visit. So the screener could ensure that the hearing sensitivity of the participants was within normal range during the whole study, both ears were screened at 500, 1000, 2000, and 4000 Hz at each visit. In addition, impedance measurements were completed on all but two participants (they had PE tubes).

The first visit was scheduled at the end of the second quarter. Preevaluation and fitting of the hearing aids were conducted over Christmas break. The unaided speech recognition in quiet was measured with the

Table 2. Summary of Individual Errors on ACPT at Different Test Intervals

	Unaided in Quiet/ errors			Unaided in Noise/ errors			Aided Noise at 2-week/ errors			Aided Noise at 6-month/ errors		
Subject	Omission	Commission	Total	Omission	Commission	Total	Omission	Commission	Total	Omission	Commission	Total
2	13	9	22	9	6	15	20	5	25	14	1	15
3	1	1	2	20	1	21	7	3	10	9	0	9
4	0	0	0	12	4	16	3	2	5	2	5	7
5	3	0	3	22	3	25	14	3	17	27	6	33
6	3	2	5	4	1	5	10	6	16	12	6	18
8	2	2	4	13	4	17	3	7	10	5	1	6
9	2	11	13	30	1	31	10	14	24	6	14	20
10	20	4	24	55	4	59	25	7	32	23	11	34
11	14	8	22	57	10	67	31	9	40	6	4	10
12	1	0	1	4	4	8	2	1	3	3	4	7
14	4	1	5	26	2	28	17	0	17	27	1	28
15	10	5	15	24	7	31	24	5	29	15	4	19
17	5	0	5	11	2	13	50	2	52	35	7	42
Average	*6.0*	*3.3*	*9.3*	*22*	*4*	*25.8*	*17*	*5*	*21.5*	*14*	*5*	*19.1*
SD	*6.2*	*3.8*	*8.7*	*17*	*3*	*18.5*	*14*	*4*	*14.2*	*11*	*4*	*11.9*

NU–6 words. The noise level needed for measuring the NU–6 words in noise for all subsequent testing was determined as well. Finally, the unaided performance of the ACPT was measured in quiet and in noise. The hearing aids were then fitted. Because of time constraints, no aided testing was done.

The second visit was scheduled for 2 weeks after the initial visit. The third visit was scheduled at 3 months postfitting, and the fourth visit was scheduled at 6 months after the first visit (at the end of the school year). At the second, third, and fourth visits, speech-in-noise testing using the NU–6 lists was conducted in the aided condition with the hearing aids set in omnidirectional alone (no NR), omnidirectional with NR "on," and directional microphone with NR "on" modes in a counterbalanced manner across participants. ACPT was also measured in noise at the 2-week and 6-month visits with the hearing aids set to directional microphone and NR "on." In addition, participants reported on the identity of the hearing aid program they used, as well as on the frequency with which they had used the program since the previous visit. Participants returned the questionnaires during the last visit. Those who desired to purchase the study hearing aids also discussed the purchase agreement and warranty.

RESULTS

ACPT

Table 2 summarizes the number of each type of error (omission and commission) on the ACPT for each individual participant at the three test intervals (initial, 2-week, and 6-month). The data were based on 13 participants (because #1, #13, and #16 withdrew, and #7 was uncooperative on the test during the last visit). Comparing the fourth column (unaided in quiet: total) and the seventh column (unaided in noise: total), one can see that all but 1 participant had fewer errors in the "quiet" condition than in the "noise" condition. On average, 9.3 errors were made in quiet, and 25.8 errors were made in noise. The variability in performance among participants was much lower in quiet than in noise (*SD* of 8.7 errors in quiet versus 18.5 errors in noise). Interestingly, most of the errors were omissions (or inattention), even for participants with a diagnosis of ADHD.

Table 2 also shows the performance in noise at the 2-week (Aided Noise at 2-week) and 6-month (Aided Noise at 6-month) evaluations. Two observations are apparent. First, the performance in the unaided quiet condition was still better than that in noise, even in the aided conditions. In addition, the variability in performance in the aided noise condition was greater than in the unaided quiet condition (*SD* of 8.7 errors in quiet versus 14.2 errors at 2 weeks and 11.9 errors at 6 months). The variability in the aided noise condition, however, was lower than that in the unaided noise condition (*SD* of 18.5 errors). Second, the performance in noise showed a slight improvement over time (averages of 26, 22, and 19 errors at the initial, 2-week, and 6-month evaluations, respectively).

Figure 2 provides a graphic display of the ACPT scores measured in noise between the unaided and the aided conditions at the two evaluation periods. The majority of the data points are below the diagonal, suggesting that the aided performance was better than the unaided performance. On average, the number of errors made in the aided noise condition was 22 (*SD* of 14.2 errors) at the 2-week evaluation and 19 (*SD* of 11.9 errors) at the 6-month evaluation (versus 26 in the unaided noise condition; *SD* of 18.5 errors). In addition, the Pearson correlation between unaided performance in noise and aided performance in noise

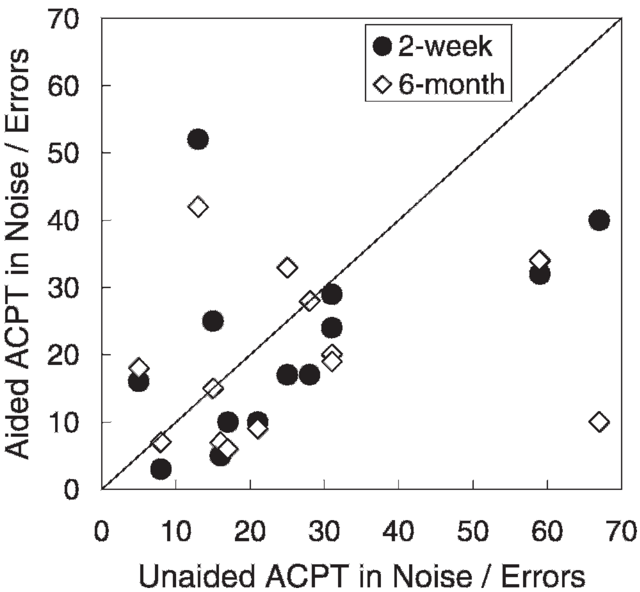

Figure 2. Number of errors participants made on the Auditory Continuous Performance Test (ACPT) in noise between the aided condition (y axis) and the unaided (x axis) conditions.

was moderate but nonsignificant (r = 0.48 at the 2-week visit and r = 0.15 at the 6-month visit, $p > 0.05$). However, the correlation coefficient between aided conditions at 2 weeks and 6 months was statistically significant (r = 0.63, p = 0.02).

A one-way Analysis of Variance (ANOVA) was performed to evaluate the significance of the difference in total ACPT error scores among the different test conditions (unaided in quiet, unaided in noise, aided in noise at 2 weeks, aided in noise at 6 months). Results show a significant difference in error scores among test conditions ($F(3, 36) = 5.72$, $p < 0.05$). Post hoc tests using a paired samples Bonferroni t test indicate that performance in the unaided noise condition was significantly poorer than unaided performance in quiet ($t = 4.36$, $p < 0.008$) but not from aided performance in noise during the two follow-up visits. Although there appeared to be a slight improvement (fewer errors) over time, the aided noise performances at the 2-week and 6-month visits were not significantly different from each other ($t = 0.78$, $p > 0.008$). The large variability in the children's performance may have also masked any observable effects. It is possible that the noted difference originated from a potential learning

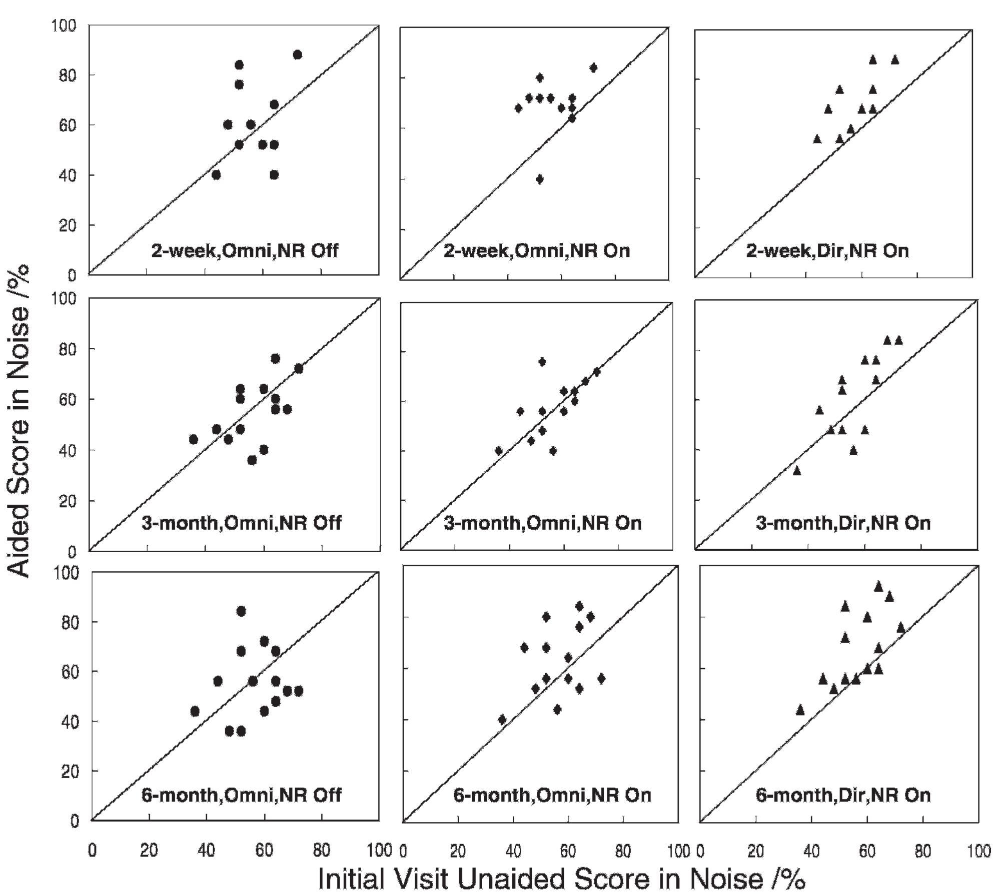

Figure 3. Scatter plots of aided Northwestern University word-list (NU–6) scores (y axis) versus unaided scores (x axis) at different hearing aid settings and visits. Three subjects (#2, #5, and #7) had missing data at 2-week.

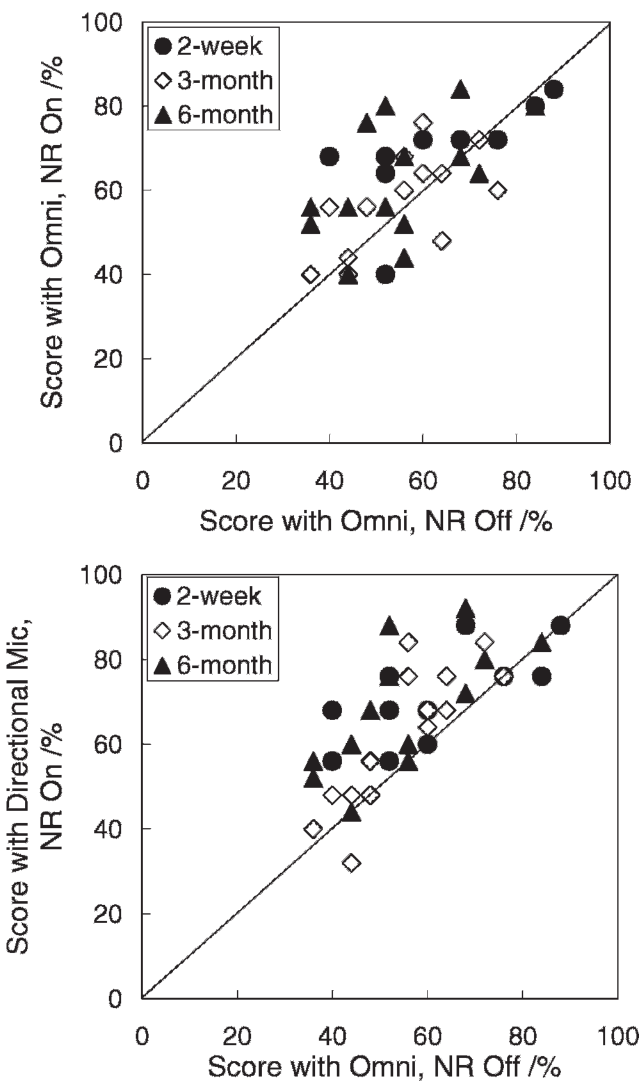

Figure 4. Scatter plots of Northwestern University word-list (NU–6) scores using different hearing aid settings: (a) omnidirectional (omni) with noise reduction (NR) on versus omni with NR off; (b) directional with NR on versus omni with NR off.

effect of the test. More subjects are needed to fully evaluate the effect of hearing aids on the ACPT.

NU–6

Figure 3 shows the scatter plots of aided NU–6 scores in noise obtained at different hearing aid settings (omni mic alone, omni mic with NR, and dir mic with NR) plotted against the unaided NU–6 scores at the three visits (2 weeks, 3 months, and 6 months). Data above the diagonal would suggest better performance in the aided condition than in the unaided condition. On the one hand, at the 2-week visit, the scattering of the data points around the diagonal would suggest that participants performed similarly between the "omni mic, NR off" condition and the unaided condition. On the other hand, the majority (or all) of the data points are above the diagonal for the "omni mic, NR on" condition and the "dir mic, NR on" condition. The same observation was not true at the 3-month and 6-month follow-ups. Other than the "dir mic, NR on" condition measured at the 6-month interval, participants did not seem to perform better in the aided noise condition than in the unaided noise condition at the other hearing aid settings.

So researchers could determine the significance of the observed differences among test conditions and visits, a 2-factor repeated multivariate analysis (3 visits $\times$ 3 hearing aid settings) was performed. The results showed that the within-subjects visit effect was not significant ($F(2, 20) = 2.043$, $p = 0.156$) but the hearing aid setting effect was significant ($F(2, 20) = 10.691$, $p = 0.001$).

Because of the nonsignificant visit effect, the results across visits were collapsed for further analysis. Figure 4 shows the scatter plots of individual performances among the different hearing aid settings and conditions. Figure 4a shows the comparison between NR "on" and "off" when an omnidirectional microphone was used. As one can see, almost two-thirds of the data points are above the diagonal, suggesting that NR "on" yielded a higher performance in noise for at least two-thirds of the participants when an omnidirectional microphone was used. Figure 4b shows the comparison between "dir mic with NR on" and "omni mic with NR off." For this comparison, all but two of the participants performed the same or better with the "dir mic + NR" than with the "omni mic alone" condition. On average, the performance with the "dir mic and NR" was 3.9% better than with the "omni mic with NR" and was 9.7% better than with the "omni mic alone" and the "unaided" conditions. The performance in the "omni mic and NR" condition was 5.8% better than in the "omni mic alone" and the "unaided" conditions. These results suggest that the combination of directional microphone and NR could be more beneficial for speech understanding in noise than just the "omni mic alone" and the "omni mic with NR" conditions.

A paired samples t test with Bonferroni showed that the scores measured with "dir mic with NR" were significantly higher than the scores measured with "omni mic alone" ($t = 5.628$, $p < 0.017$) and "omni mic with NR" ($t = 2.535$, $p < 0.017$). Moreover, the paired samples t test with Bonferroni also showed that "omni mic with NR" was significantly better than "omni mic without NR" ($t = 3.026$, $p < 0.017$).

Because unaided NU–6 scores were obtained only at the initial fitting (a result of time constraints), a separate analysis was conducted to examine whether the unaided scores were different from the aided scores for each of the hearing aid settings at each subsequent visit (2-week, 3-month, and 6-month). A paired samples t test with Bonferroni (based on 11 valid cases because the data of three participants were missing at

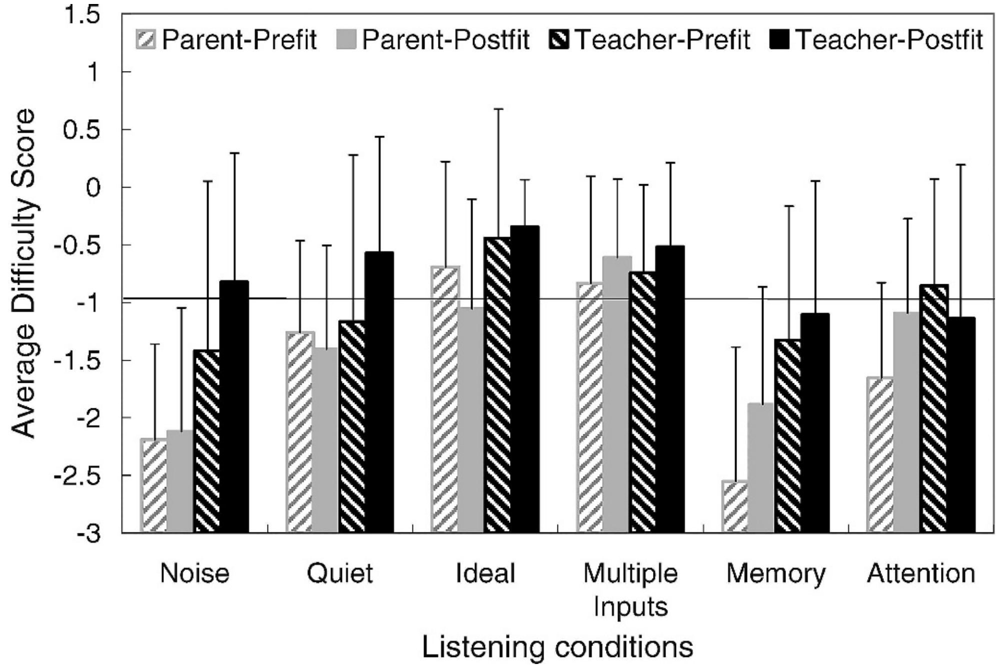

Figure 5. Averaged Children's Auditory Processing Performance Scale (CHAPS) scores for different criterion categories measured before (patterned bars) and after (solid bars) the study. The ratings provided by the teachers and parents are displayed side-by-side for comparison. The magnitude of the *SD* is also indicated.

the 2-week visit) indicated that the "dir mic with NR" ($t = -5.54$, $p < 0.008$) and the "omni mic with NR" ($t = -3.31$, $p < 0.008$) conditions were significantly better than the unaided condition at the 2-week visit. This finding was also true at the 6-month evaluation, where the "dir mic and NR" was significantly better than the unaided condition ($t = -3.61$, $p < 0.008$). However, the unaided scores were not significantly different from the aided scores at the 3-month visit. Despite such an aberration, the overall results support that NR with an omnidirectional microphone or a directional microphone could significantly improve the speech in noise performance of these participants.

CHAPS

Figure 5 compares the averaged CHAPS scores of all participants between the prefitting and the 6-month postfitting conditions reported by their parents and teachers. As a reminder, a score that is lower than -1.0 for any category would suggest at-risk behavior for that category and may affect school performance.

Figure 5 shows that teachers and parents had different views about the problems encountered by the study participants and about the efficacy of amplification. The teachers rated the participants to be at risk in the "noise," "quiet," and "memory" categories during the prefitting. Their perceptions of major improvements were noted in the "noise" and "quiet" categories, where the scores improved from -1.5 and -1.2 to -0.8 and -0.5, respectively. This improvement brought the performance from the "at risk" level to the "not at risk" level in these two categories. Even with the use of hearing aids, the participants' ratings on the "memory" and "attention" categories were still at a level that may suggest at-risk behaviors. It is also noted that the rating on the "attention" category actually decreased slightly with the use of hearing aids.

For the parents, the typical participant was "at risk" in all but the "ideal" and "multiple inputs" categories. The major improvement, however, was noted only in the "memory" and "attention" categories, where the scores improved from -2.6 and -1.8 to -2.0 and -1.1, respectively. Despite the improvement, the performance in both categories (as well as in the other categories) was still considered at risk.

A repeated multivariate measure of two within-subjects factors (with and without hearing aids $\times$ 6 performance categories) and one between-subjects factor (rater = parent and teacher) was performed to examine any significant differences among conditions. Results showed that the within-subjects factor of hearing aid was not significant ($F(1, 1) = 2.202$, $p = 0.154$), but performance category was significant ($F(5, 5) = 16.127$, $p < 0.05$). The results of the analysis also indicate that the interaction of performance category by the rater was significant ($F(5, 95) = 2.622$, $p < 0.05$). The overall interaction effect of hearing aid $\times$ performance category $\times$ rater was significant ($F(5, 95) = 3.545$, $p < 0.05$). These results suggest that the use of hearing aids did not affect the overall performance.

Table 3. Summary of Participants' Impressions of the Hearing Aids

Subject	Do you wear your aids at School?	Do you wear your aids at Home?	Mind wearing aids?	Hear teacher better?	Hear parents better?	Which program used?
2	yes	yes	no	a lot better	a lot better	1
3	yes	yes	no	a lot better	a lot better	1*
4	yes	no	no	a lot better	a little	1
5	yes	no	no	a little	same	2
6	yes	yes	yes	a lot better	a lot better	2
7	sometimes	no	yes	same	same	1
8	yes	yes	no	a lot better	a lot better	1
9	yes	yes	no	a lot better	a lot better	1*
10	yes	yes	no	a lot better	a lot better	2
11	yes	sometimes	no	a lot better	a lot better	1
12	yes	no	no	a little	a little	1
14	yes	yes	no	a lot better	a lot better	2
15	yes	yes	no	a lot better	a lot better	1
17	yes	no	yes	same	a little	1

*These participants forgot to switch programs (and the ''omni mic alone'' program was in the default position).

However, the manner in which parents and teachers rated the participants and the performance categories that were judged by these raters were significantly different.

Impressions of Hearing Aid Use

Participants and their parents were surveyed on their overall impression of the study hearing aids at the end of the 6-month period. All the parents were positive about the trial with the study hearing aids. Two (#10 and #11) indicated that their children's voice level was lowered to a more acceptable level. Four (#2, #6, #7, and #14) reported that their children could hear much better in background noise. Five of the parents (#3, #6, #8, #9, and #10) reported that their children were more focused while wearing the hearing aids. Six (#2, #6, #7, #8, #11, and #14) reported that their children were more responsive when called from a distance (e.g., the next room). Three (#6, #8, and #10) noticed that their children did not ask as many questions when watching TV, and four (#3, #6, #9, and #14) reported that their children's grades improved. Interestingly, subject #6 did not favor the study hearing aids, even though he reported benefiting from their use. The parents of participants #3, #9, and #10 purchased the study hearing aids at the end of the study. At the time of this write-up (12 months after the last session), these three participants continued to use the study hearing aids in and out of school, with positive comments.

The summary of the participants' survey (five questions) is presented in Table 3. The results show that 11 of the 14 participants did not mind wearing the hearing aids, even though only half of them wore the hearing aids consistently at home. Participants #5, #6, #7, and #17 did not favor the hearing aids. It should also be noted that the majority of these children reported hearing their teachers and parents "a lot better," whereas those who objected to wearing the hearing aids did not report the same success. Almost all of the children reported that they consistently wore the hearing aids in school. Of the 14 children, 10 reported using program 1 (omni mic only without NR) mostly in their daily activities. However, it must be pointed out that two of the children (shown with asterisks in Table 3) forgot to switch programs (and the "omni mic alone" program was in the default position). For those who tried both hearing aid programs (about one-third), the majority preferred the "dir mic and NR" program to the "omni mic alone" program. The majority of the participants left the hearing aid in their preferred program most of the time. As reported above, only 3 of the 14 children decided to purchase the study hearing aids at the end of the trial; financial issues were cited as the main reason for nonpurchase.

DISCUSSION

The present study was a preliminary attempt to evaluate the feasibility of personal amplification in improving the speech in noise performance and listening behaviors of children diagnosed with APD. Specifically, the use of minimal gain, open-ear fitting hearing aids with a directional microphone and NR algorithm was examined. It was observed that such a device improved the speech-in-noise performance of the participants but might not improve their attention in noise. Although some parents and teachers noted improvements in their children's behaviors during their daily activities, the large variability among the respondents precluded the results from reaching statistical significance. The use of personal hearing aids, though acceptable to most participants, should be validated further with more participants before a more definitive recommendation may be made.

Optimal Hearing Aid Characteristics

The rationale for open-ear fittings for children (i.e., minimal gain requirement, instant fit, comfort, ease of handling) in this study seemed justified in that almost all the children reported acceptance of the hearing aids and wore them in at least some of their daily environments. From the acoustic standpoint, none of the participants reported any negative reactions from the use of the hearing aids—such as increased occlusion effect, loudness discomfort, or physical discomfort—while wearing them. However, from the psychological standpoint, the use of personal amplification may add stress to some of the children. This stress was evidenced in three children who withdrew from the study after only one visit. Some of the stress could come from peer pressure and the stigma associated with the use of hearing aids. If such were the reasons, one would expect the use of FM to result in similar difficulty. Since the time of the study, open-fit BTEs have become even smaller and more colorful. Perhaps this aesthetic improvement will improve the acceptance of hearing aids in this population. Nonetheless, psychological or social stress or both can be a potential concern that should be addressed if hearing aids (or FM) are to be used by this population.

The initial attempt of 10–15 dB recommended real-ear insertion gain for soft sounds could be appropriate for most children. The fact that the sensogram was lowered to 30 dB HL (from 40 dB HL) in the midfrequencies for six children would suggest that this initial gain between 1000 and 2000 Hz may be slightly too much for some. In the future, a mild gain of around 10 dB for soft sounds above 1000 Hz may be sufficient.

The real-ear aided gain of 10–15 dB in the 2000–3000 Hz region is similar in magnitude to the REUR provided by the open-ear canal. This similarity in real-ear gain means the amplification provided by the hearing aid in its current setting (for a hearing loss of 40 dB HL at 3000 and 4000 Hz) does not add appreciably to the audibility of the high frequency sounds above 2000 Hz. In other words, the natural resonance of the ear canal has already enhanced the audibility of the 2000–3000 Hz region (as in an open-fit). It is not necessary for an open-fit hearing aid to provide amplification in this frequency region. Thus, if the gain requirement of a hearing aid for normal hearing children with APD is simply 10–15 dB of aided gain between 1000 and 2000 Hz (for soft sounds), such a gain requirement can be met easily by almost any hearing aids—even those without a special feedback algorithm or extended bandwidth considerations.

The hearing aid requirement would be different if a 10 dB insertion gain (instead of aided gain) is desired. A 10 dB insertion gain in the 2000–3000 Hz region would mean an aided gain of 20–25 dB if one assumes that the ear-canal resonance is 10–15 dB. This gain could push the hearing aid to the verge of feedback (Dillon, 2001) unless active feedback cancellation is available on the hearing aids. If one considers that the hearing of the study population is normal and keeps in mind the subjective impressions from the study participants, an aided gain of 10 dB would seem sufficient.

An important finding in this study is that amplification alone did not improve the children's speech recognition in noise over the unaided condition. This result was seen on the NU–6 words in noise where the unaided scores were similar to the aided scores when an omnidirectional microphone alone was used. Thus, simply providing additional gain, on the one hand, in the midfrequency region is not sufficient to improve speech intelligibility in noise for this group of participants. On the other hand, Figure 3 shows that when noise reduction was included in the amplification, either with an omnidirectional microphone or with a directional microphone, a significant improvement in speech understanding in noise was noted. This finding was especially true for the "dir mic plus NR" mode, where all the participants received a higher score than in the unaided noise testing.

The improvement of speech understanding in noise with the use of a directional microphone is not surprising. As noted earlier, Kuk et al (1999) and Gravel et al (1999) had reported speech improvement in noise in hearing-impaired children with such a technology. On the one hand, such an improvement had also been noted in adults with an open-ear device (Kuk et al, 2005). On the other hand, no studies to date have reported speech intelligibility improvement in noise with an NR algorithm, despite some studies reporting no intelligibility loss with such an algorithm (Marcoux et al, 2006). The difference in the subject population is likely the main reason for the difference in observations. The availability of the NR algorithm may have reduced the output of the hearing aid and resulted in a more comfortable listening condition for children with APD. Perhaps it is the subjective comfort provided by the NR algorithm, rather than the improvement in audibility in noise, that facilitated overall performance. Nonetheless, these observations would suggest that thin-tube, open-ear fittings with mild-gain hearing aids with NR and directional microphone technology are feasible attempts in improving the speech-in-noise performance of children with APD.

It is less certain that the use of "dir mic and NR" improved the attention of these children. Although Table 2 shows a significant reduction in errors made by subjects #3, #4, #9, #10, and #11 on the ACPT, other participants showed an opposite pattern. Because the test was presented only once at each trial and some of these children were diagnosed with ADHD, it is likely that there will be large variability in the measured data. Presenting the test more than once during a trial could minimize the variability, but it would also decrease the attentiveness of the children because of the prolonged testing. Furthermore, repeated testing with the same test would undoubtedly result in learning effects that would also confound the interpretation of the results. To evaluate more definitively the efficacy of hearing aid processing on attention, one may need to have more equivalent versions of the ACPT for repeated testing. Furthermore, one would need to estimate the potential learning effect associated with the test in order to partial out such an effect. Alternatively, testing with more subjects may also reduce the variability associated with this test and this population of subjects. That possibility should be further explored.

Effects of Acclimatization?

The current study was conducted over a period of 6 months to allow the effects of acclimatization, if present, to be observable. Unfortunately, that was not the case. Not only did we not observe any effect of acclimatization with the use of the study hearing aids, but also we observed the best speech in noise performance at the 2-week visit and the poorest performance at the 3-month visit (Figure 3). The performance at the final visit was better than at the third visit but was similar to the second (2-week) visit results.

It is unclear why the results at the third visit were poorer than the results at other visits. The most likely explanation was the variability in the participants' performance and the distractibility of the subject population. Perhaps the children were most cooperative during the second visit because of the novelty of the hearing aids and the novelty of the research study. During the third visit (which was 3 months postfitting), the novelty of the experience might have worn off and the children might have been less motivated to participate. This possibility could explain the poorer performance on the NU–6 testing during the third visit; it could also explain the lack of any acclimatization effect. Regardless of the possibilities, the difficulties associated with conducting research in a pediatric population (such as the increased variability, the need for repeated testing and more subjects, the time constraints, and the effect of the etiology on the measured outcome) should be considered before the study.

Effectiveness in the Eyes of the Beholder?

The present study showed that the use of personal hearing aids might improve the everyday behaviors of children with APD; however, the areas of improvement seem to be different, depending on who was doing the judging. Specifically, on the CHAPS questionnaire, the teachers reported significant improvements with personal amplification in the areas of "noise" and "quiet" listening, whereas the parents reported no difference in performance in those areas. However, the parents indicated improvement in "memory tasks" and "attention tasks," whereas the teachers reported little changes in these areas. Both groups reported similar nonrisk performance in the "ideal" and "multiple environments" listening categories.

It is not unusual for teachers and parents to perceive children's behaviors differently. Research in other areas such as ADHD and other behavioral problems is filled with similar observations. For example, a study that evaluated 184 children with ADHD showed that teacher ratings outperformed parent ratings when considering sensitivity, specificity, and overall classification accuracy (Tripp et al, 2006). Other studies also showed low-to-moderate parent–teacher agreement when reporting on children with behavioral problems.

The reason for the difference in teacher–parent observations is unclear. One possibility may be the inherent bias or expectation of each group for the use of personal amplification. On the one hand, parents—by enrolling their children in the study—may have hoped for personal hearing aids to improve their children's auditory processing skills. With such a bias, they may have focused their attention directly on memory and attention tasks. Teachers, on the other hand, may view personal hearing aids as devices that only amplify sounds and not as devices that change the neural processing of the child. Consequently, their attention was focused on aspects that were more directly related to hearing aid processing—such as improved listening in noise and in quiet—and not to processing such as attention and memory tasks. Future studies may consider educating the teachers and parents on the nature of auditory processing disorders and on hearing aids before the data collection so studies can examine if such a bias may be minimized.

CONCLUSIONS

Despite the positive outcomes observed in the children's improved speech understanding in noise, the large variability has led us to be cautious in concluding that hearing aids are necessary for children with APD. Indeed, hearing aids improved the children's performance in noise during clinical testing, and several students (#3, #6, #9, and #14) reported better grades consequent to the use of hearing aids. But at least three considerations—(a) the lack of a statistically significant difference on the ACPT and CHAPS, (b) the three students who withdrew from the study because of increased awareness and/or stress, and (c) the small number of students (three) who decided to continue using the hearing aids after the study—caution us to be tentative when managing this disorder with amplification. The success of amplification would also depend on the children's motivation and their environments. These issues would need to be considered before aiding the child with APD. But if personal amplification is to be attempted, the use of a miniature mild-gain directional BTE with noise reduction in an open-ear fitting would have the best chance of success. Additional studies with more subjects should be conducted to ascertain the efficacy of personal amplification on children with APD.

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