Effect of Minimal Hearing Loss on Children's Ability to Multitask in Quiet and in Noise

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There is a growing body of evidence that children with minimal hearing loss (HL) are at an increased risk for speech and language delays, poor academic performance, and social dysfunction compared to their peers with normal hearing (NH) (Bess, Dodd-Murphy, & Parker, 1998; Blaire, Peterson, & Viehweg, 1985; Davis, Elfenbein, Schum, & Bentler, 1986; Kenworthy, Klee, & Tharpe, 1990). In fact, several studies have reported that children with minimal HL experience many of the same difficulties as those experienced by children with more severe HL (Davis et al., 1986; Kenworthy et al., 1990). Unfortunately, there remains a prevailing perception among physicians, parents, and teachers that the consequences of minimal HL in childhood are likewise minimal. Therefore, research to reveal the many consequences of minimal HL for children is warranted.

ABSTRACT: **Purpose:** The purpose of the present study was to examine the effect of minimal hearing loss (HL) on children's ability to perform simultaneous tasks in quiet and in noise.
Method: Ten children with minimal HL and 11 children with normal hearing (NH) participated. Both groups ranged in age from 8 to 12 years. The children categorized common words (primary task) while completing dot-to-dot games (secondary task) in quiet as well as in noise presented at 0 dB and +6 dB signal-to-noise ratios (SNRs). It was hypothesized that the children's progression through the dot-to-dot games would slow as they encountered more difficult listening environments. This hypothesis was based on the theory that listeners have limited cognitive resources to allocate to any combination of tasks.
Results: The dot rate of both groups decreased similarly in the multitasking conditions relative to baseline. However, no other differences between groups or listening conditions were revealed. Significantly poorer word categorization was observed for the children with minimal HL in noise.
Conclusion: These data suggest that children with minimal HL may be unable to respond to a difficult listening task by drawing resources from other tasks to compensate.

KEY WORDS: children, hearing loss, listening effort, noise, multitasking

Minimal HL

Minimal HL has generally been defined as a group of configurations that include mild, unilateral, and high-frequency hearing thresholds (Bess et al.,1998; Tharpe & Bess, 1999). With some minor variations in definitions across studies, mild HL is that for which one or more thresholds fall between 20 dB HL and 40 dB HL, unilateral HL is characterized by normal thresholds in one ear (≤15 dB HL) with some degree of HL in the other ear, and high-frequency HL consists of normal thresholds at frequencies below 4 kHz (≤15 dB HL) and thresholds that exceed 25 dB HL at 4 kHz and greater. One reason for collapsing these configurations into the single category of minimal HL is that hearing aids are not often prescribed in these cases as the benefits from amplification can be limited (Kochkin, Luxford, Northern, Mason, & Tharpe, 2007). For example, high-frequency losses are not often amplified because most commercially available hearing aids do not provide amplification at frequencies greater than 4 kHz. Likewise, the impaired ear of children with unilateral losses may be so severe that a hearing aid will provide little or no useful amplification.

In one of the largest studies of children with HL, the demographic and psychoeducational records of 1,250 children with HL attending Iowa schools during the 1976–1977 school year were evaluated (Davis, Shepard, Stelmachowicz & Gorga, 1981; Shepard, Davis, Gorga, & Stelmachowicz, 1981). The sample included children in preschool through high school. The HLs of these children

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were classified by the degree (i.e., mild to profound on the basis of the pure-tone average [PTA]) and type (i.e., conductive, high frequency, sensorineural/mixed) of loss. Compared to standardized test scores for NH children, the academic achievement test scores and intelligence quotients of the children with minimal HL were only slightly reduced, if at all. The results of the language measures, on the other hand, suggested a gap between the children's language age and their chronological age that increased with grade level. For example, the vocabulary of the children with minimal HL was as much as 3 years behind that of their NH peers by the time they reached 8 years of age.

In a somewhat smaller study, Davis et al. (1986) evaluated the social, academic, and communication status of 40 children with longstanding sensorineural HL. The children possessed a wide range of hearing levels (PTAs of 15 dB HL to 73 dB HL) and spanned an equally wide range of ages (5 to 18 years). The results showed that on average, the children with HL performed below the levels of their NH peers on a number of standardized tests. Although the children's performance on clinical measures of speech perception was found to be related to their degree of HL, a similar relationship was not observed between hearing level and several language measures. The authors concluded that children's success with language and academics may not be easily predicted by the degree of the HL. The results suggest a disconnect between audiologic measures (e.g., pure-tone audiometry, speech perception) and measures of communication (e.g., vocabulary, verbal reasoning) for children with all degrees of HL, including minimal losses.

Bess and colleagues evaluated the hearing status and academic achievement of 1,228 schoolchildren in Grades 3, 6, and 9 (Bess et al., 1998). They reported a prevalence of approximately 5.4% for minimal HL in this group. Of these children, more than one third were failing in the areas of academics, attention, and communication. That is, children with minimal HL were 4 times more likely to experience communication problems compared to their NH peers and nearly 3 times more likely to have difficulty in academics. Children with minimal HL were also more likely than NH children to repeat one or more grades, and retention rates increased with grade level compared to school district norms. Specifically, approximately 30% of the third-grade children with minimal HL had repeated at least one grade, whereas nearly half (50%) of the ninth-grade children had repeated a grade. Finally, these children also experienced greater stress and behavioral problems. The results were consistent with similar studies that evaluated the personality inventories of children with HL and found significantly higher tendencies toward aggressiveness compared to NH children (Davis et al., 1986).

Other researchers have shown that children with minimal HL may be at risk academically due, in part, to their poorer speech perception in the classroom (Bess, 1985; Crandell, 1993; Crandell & Smaldino, 2000). For example, Crandell investigated speech recognition in children with minimal HL in signal-to-noise ratios (SNRs) that are typical of elementary school classrooms. Twelve children with minimal HL and 12 NH children (ages 5–15 years) participated in the study. Minimal HL was defined as a PTA between 15 dB HL and 30 dB HL in at least one ear, with no threshold greater than 45 dB HL at any frequency. The sentence recognition of each child was >90% in quiet. Sentences were presented at 65 dB SPL in multitalker babble at SNRs of +6, +3, 0, –3 and –6 dB. The results showed that, overall, the average performance of both groups decreased as SNR decreased. More importantly, the children with minimal HL performed more poorly than the NH children at all SNRs, and the difference between the groups increased as SNR decreased. For example, the performance of the children with HL was 13% poorer than that of the NH children in the +6 dB SNR condition and 33% poorer in the –6 dB SNR condition. These results suggest that although typical classroom noise is detrimental to the speech perception of all children, children with minimal HL are at a significantly greater disadvantage in that they cannot withstand the same levels of noise as their NH counterparts.

Multitasking

Although a few studies have investigated the effects of noise on the speech perception of children with minimal HL, far less is known about how these children manage multiple demands on their attention. For example, elementary schoolchildren may be asked to attend to a written assignment while listening to verbal instructions, whereas older children may be required to take notes while listening to a lecture. Additional demands on their attention may come from classmates or even noisy events outside the classroom. It is possible that the poorer academic achievement of children with minimal HL may be due, in part, to the manner in which they manage multiple, simultaneous events.

One method for examining multitasking is a dual-task paradigm in which the child performs two different tasks simultaneously (e.g., pressing a button when a light appears while repeating words). This paradigm is useful for estimating listening effort by observing changes in performance for one task relative to the difficulty of the other task. In theory, listeners have limited cognitive resources to allocate to any combination of tasks. When the demands of one task increase, greater effort may be allocated to that task, leaving fewer resources with which to attend to the other task. In a dual-task paradigm, a secondary task is used to measure the residual resources that are not allocated to the primary task. That is, reduced performance on a secondary task may indicate that the listener is experiencing increased difficulty with the primary task. For children with minimal HL, this may mean that fewer cognitive resources are available to maintain performance on a secondary task when the primary task involves listening.

Dual-task paradigms have been used in a number of studies involving adults to examine the cognitive resources necessary to process auditory stimuli (Downs, 1982; Downs & Crum, 1978; Feuerstein, 1992; Rakerd, Seitz, & Whearty, 1996; Rossiter, Stevens, & Walker, 2006). Downs and Crum examined the ability of NH adults to learn word pairs in quiet and in noise while also responding to a probe light presented at random intervals throughout the test period. They reported a significant increase in reaction time to the probe light (i.e., response time was slower) when noise was added to the listening environment. The results suggest that the presence of noise increased the difficulty of the learning task, which reduced the listener's attention to the probe light.

Rakerd et al. (1996) examined the ability of adults with HL to remember a series of digits while attending to a passage of speech for which they answered questions regarding content. In separate studies, the performance of adults with congenital/early-onset HL and adults with acquired HL was compared to that of NH adults. In both studies, the adults with HL were able to recall significantly fewer digits than the NH adults. The results suggest that the adults with HL allocated more cognitive resources to perceiving and understanding the passage of speech than did the NH adults.

Finally, Rossiter et al. (2006) used a dual-task paradigm in a clever application to study the cognitive load that tinnitus places on adults when they attempt to perform non-auditory tasks. The authors theorized that the cognitive capacity of adults with tinnitus is reduced because their attention is constantly oriented, to some degree, to their tinnitus. The performance of 19 adults with constant, moderate tinnitus was compared to that of 19 adults without tinnitus. The groups were matched for age, education, and occupation but not for hearing level because the stimuli were presented visually. Each participant took part in three tasks. The first was a baseline visual reaction-time task in which the listener clicked on a small gray rectangle that appeared intermittently in the center of a computer screen. The second and third conditions involved dual-task paradigms in which visual reaction time was measured while reading words (low demand) or categorizing words (high demand). In the low-demand task, the participant read aloud a series of words that were displayed one at a time on a computer screen. In the high-demand task, the procedures were the same except that the participant stated the category to which each word belonged (i.e., cooking, animal, or seascape). The error rate for reading and categorizing was calculated as well as the reaction time to the gray rectangle. It was expected that reaction time would increase when the participants categorized the words rather than simply reading them because categorization would require more cognitive resources. The results revealed a significant increase in reaction time during the dual-task conditions and a significant group effect. That is, reaction time was slower for the participants with tinnitus than for the participants without tinnitus. The results of this study suggest that auditory distractions (like tinnitus) can affect non-auditory tasks.

Overall, the results of previous studies suggest that when adults are faced with competing tasks, they will reduce their performance on one task in order to maintain their performance on another task. Because the adults were instructed to place a higher priority on the speech-based tasks (e.g., word recognition, word categorization), they drew the needed cognitive resources from the secondary tasks (e.g., reaction time, digit recall) as predicted. If children with minimal HL respond in the same manner, they may have difficulty attending to multiple tasks if one of those tasks involves listening.

Multitasking in Children

To date, only two studies have used a dual-task paradigm to examine the allocation of cognitive resources in children with HL (Hicks & Tharpe, 2002; Stelmachowicz, Lewis, Choi & Hoover, 2007). Hicks and Tharpe examined 14 children with mild-to-moderate HL and 14 NH children. Both groups were between the ages of 6 and 11 years. The children were asked to repeat words presented through loudspeakers at 70 dB SPL while pressing a button when a probe light appeared. The words were presented in quiet and in multitalker babble at +20, +15, and +10 dB SNR. The children with HL wore their personal hearing aids. At the end of the SNR condition, the children were asked to rate the level of difficulty that they experienced. Although there was no significant difference in difficulty ratings between the groups, the children with HL showed consistently and significantly slower reaction times than did the NH children. However, the reaction time for both groups remained unchanged across SNR conditions. In addition, the children with HL had significantly lower word recognition scores (primary task) in all conditions as compared to the NH children, and the gap in performance between the groups increased as the SNR decreased. These results are in conflict with those for adults in that the children's reaction time was expected to increase as the speech perception task became more difficult (Downs, 1982; Downs & Crum, 1978; Feuerstein, 1992; Rakerd et al., 1996; Rossiter et al., 2006). Instead, the children's performance on the two tasks appears to be unrelated.

Finally, Stelmachowicz et al. (2007) examined listening effort in 32 NH children and 24 children with mild-to-moderately severe HL. All of the children were between the ages of 7 and 14 years. The children were asked to repeat monosyllabic words while attempting to retain a series of digits presented visually before the word recognition task. Two word-recognition conditions were presented in which the stimuli were low-pass filtered at either 5 or 10 kHz. All words were presented in speech-shaped noise at an SNR of +8 dB. The purpose of the study was to determine the level of effort that the children experienced when listening to stimuli made up of two different bandwidths. The results revealed a significant effect of bandwidth (i.e., higher performance for the words presented in the 10 kHz bandwidth condition relative to the 5 kHz condition). However, both groups performed similarly on the digit recall task in each of the two bandwidth conditions. The lack of effect for the secondary task is similar to the results of Hicks and Tharpe (2002) and suggests that children may not redirect their cognitive resources as adults do when speech perception becomes more difficult.

The disparity between the performance of children and the performance of adults suggests that these groups may approach multitasking situations differently. That is, adults may have the ability to redirect their cognitive resources from one task to another, whereas children may not. However, the differences across groups may also be due to the fact that the secondary tasks that the children were asked to do in previous studies were somewhat novel to them (pressing a button to extinguish a light, memorizing a series of numbers), which may have captured their attention more than the simple word recognition task was able to do. The purpose of the present study was to examine the effect of minimal HL on multitasking in children using tasks that are more common to children, that is, dot-to-dot games and a word categorization task. To increase the difficulty of the listening task, a broadband noise masker was used. Although a multitalker competitor was considered, the impact of the broadband noise masker was expected to have a lesser effect on perception while still increasing the difficulty of the task. It was hypothesized that for all children (a) word categorization would remain unchanged in each of the multitasking conditions relative to baseline, (b) dot rate would decrease in the quiet multitasking condition, and (c) dot rate would decrease further in noise. Furthermore, it was hypothesized that the dot-to-dot rate of the children with minimal HL would be reduced significantly more than that of the NH children.

METHOD

Participants

Ten children with minimal HL and 11 NH children participated in this study. The children in both groups were between the ages of 8 and 12 years. Table 1 lists the age of each child as well as the

Table 1. Individual hearing thresholds (in dB HL) for the children with minimal hearing loss (HL) as well as the average hearing thresholds (and standard deviation) for both the children with HL and the children with normal hearing (NH). The values in parentheses were not included in the calculation of averages. The amplification status of the children with minimal HL is also provided (B = both ears, R = right ear, L = left ear, N = no amplification). HLs are listed from mild to high frequency to unilateral. The HLs of a few children were considered combinations of two configurations and are listed at the boundaries of each category.

			Right ear						Left ear						
	ID#	*Age*	*250*	*500*	*1k*	*2k*	*4k*	*8k*	*250*	*500*	*1k*	*2k*	*4k*	*8k*	*Amp. status*
	Hearing loss														
	1	12;3	0	5	5	0	20	40	5	5	0	25	10	40	N
Mild	2	8;11	35	30	35	35	25	40	30	25	40	35	35	45	B
	3	10;11	20	20	30	30	40	40	20	20	30	35	40	35	B
	4	12;11	20	20	15	15	15	15	20	20	15	15	50	40	N
High frequency	5	12;4	10	20	25	40	45	50	20	15	25	40	45	50	B
	6	10;9	20	10	0	10	60	20	20	5	0	55	40	30	B
	7	9;0	35	20	25	80	90	(NR)	35	20	5	0	80	75	R
	8	9;4	10	15	5	0	15	30	40	25	20	35	75	80	N
Unilateral	9	8;6	(80)	(90)	(95)	(95)	(100)	(NR)	20	15	20	15	80	80	B
	10	11;1	(85)	(75)	(65)	(75)	(85)	(85)	10	10	10	10	15	15	R
	Avg.	*10;6*	*19*	*18*	*18*	*26*	*39*	*34*	*22*	*16*	*17*	*27*	*47*	*49*	
	SD	*1;6*	*12*	*8*	*13*	*27*	*26*	*12*	*11*	*7*	*13*	*17*	*25*	*22*	
	Normal hearing														
	Avg.	*10;11*	*5*	*7*	*5*	*5*	*0*	*4*	*7*	*8*	*5*	*5*	*2*	*3*	
	SD	*1;4*	*4*	*7*	*7*	*5*	*6*	*7*	*8*	*6*	*6*	*7*	*6*	*9*	

Note. Age is listed in years;months.

hearing thresholds for the right and left ears of the children with HL. Average values for both groups are provided in italics. Also listed is the amplification status of each child with HL. In keeping with the configurations described by Bess and colleagues, the HLs of the children included mild, high-frequency, and unilateral configurations (Bess et al., 1998; Tharpe & Bess, 1999). The children with mild losses are listed first followed by the children with high-frequency and unilateral losses. Note that the HLs of a few children could be considered combinations of two configurations and were placed at the boundaries of each category. All of the HLs were sensorineural in nature.

At the time of testing, normal middle-ear status was confirmed on the bases of age-appropriate norms (Nozza, Bluestone, Kardatzke, & Bachman, 1992, 1994) for a handheld tympanometer (GSI 37 Auto Tymp). Pure-tone thresholds were obtained using a standard clinical audiometer (GSI 16) and insert earphones (Etymotic, ER 3A). All testing was conducted in a sound-treated booth meeting American National Standards Institute (ANSI) standards for room noise (ANSI, 1999). Before testing, appropriate consent (parent) and assent (child) were obtained from each participant in accordance with the policies of the Arizona State University Internal Review Board. Testing required less than 1 hr, and each child was paid $10 for his or her participation.

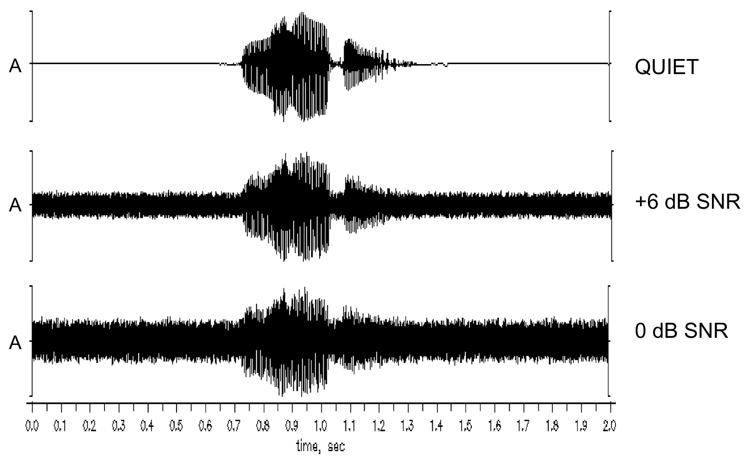
Primary Task Stimuli

A total of 99 nouns having to do with animals, food, and people served as stimuli and are listed in the Appendix. The words were gathered from a larger list of words that are used by first graders (Moe, Hopkins, & Rush, 1982). Plurals were reduced to the singular form, and only mono- and bisyllabic words were included. The words in each category (animal, food, people) were distributed equally across three lists, for a total of 30 words per list. The remaining nine words were placed in an additional list and served as stimuli for the baseline categorization task.

The words were produced by a female talker having a standard American English dialect and were digitally recorded at a sampling rate of 22.05 kHz using a microphone with a flat frequency response to 10 kHz. Individual audio files of each word were edited from the original and then equated for root mean square level. A period of silence was added at the beginning and end of each word so that the duration of each file was 2000 ms.

Two noise listening conditions and one quiet listening condition were created. The speech stimuli were presented at an overall level of 65 dB SPL in each condition. For the noise conditions, a 2000 ms broadband noise was generated at a sampling rate of 22.05 kHz. On each trial, a word was mixed with the noise and was presented to the child. The words were temporally centered within the 2000 ms sample of noise, as illustrated by the waveforms for the stimulus word "lady" in Figure 1. The noise was presented at 59 and 65 dB SPL to produce SNRs of +6 and 0 dB. All speech stimuli were delivered binaurally through earphones having a flat frequency response through 10 kHz (Sennheiser, 25D). Custom amplification was not provided due to the difficulty of providing equivalent gain parameters to all children and because some of the children did not use hearing aids.

Figure 1. Waveforms for the stimulus word "lady" in the quiet, +6 dB SNR, and 0 dB SNR listening conditions.



Secondary Task Materials

Eighteen dot-to-dot games for children were divided into three sets of six games each. The total number of dots per set was equated as closely as possible (i.e., 270, 274, and 273 dots). Two booklets containing the same 18 dot-to-dot games were created for each child. The first booklet (control) was used to obtain a baseline dot rate for each game. The control booklets were the same for each child. The second booklet (experimental) was used to obtain a dot rate for each of the dual-task conditions. The experimental booklets differed across children in that the order of the sections and the games within each section were randomized. Sections were separated by a colored piece of paper to mark the beginning and end of each section.

Procedure

All stimuli were processed using custom laboratory software designed for a standard desktop PC. Although the temporal parameters of the experiment were controlled by the laboratory software, the child's responses were self-paced. That is, a word was presented to the child (2000 ms stimulus duration), the child responded at his or her own pace (10 s response interval), the examiner entered the response immediately, and then the next stimulus was presented after a short delay (1000 ms). The examiner entered the child's responses using a computer monitor that displayed a labeled button for each category as well as a "no response" button. The examiner was not aware of the stimuli or the accuracy of the responses. A second examiner was positioned outside the sound-treated room to administer the experiment and monitor the child's performance.

The laboratory equipment was calibrated before data collection by adjusting the overall output of the transducer for a 1 kHz pure tone in a 6-cm^3 hard-walled coupler to 65 dB SPL and then documenting the voltage at the back of the earphone. Calibration was confirmed before testing each child.

Primary task baseline. Nine words were presented to each child to obtain a measure of baseline categorization performance. The child was instructed to tell the examiner the category of each word (animal, food, or people) or to indicate that he or she did not know. Labeled pictures illustrating each of the three categories were displayed to help the children recall the three choices (Figure 2). Although the three pictures were also stimulus words (one from each experimental word list), it was unlikely that the advantage significantly affected the already high performance of the children.

Secondary task baseline. A measure of baseline performance was also obtained for the dot-to-dot games. Each child was given a pencil and a control booklet opened to the first colored page with the following instructions: "You will play some dot-to-dot games while I time you. This is not a race to see how fast you can do them. You simply need to do your best. If you make a mistake, you may continue or correct your mistake. When I say 'go,' turn the page and begin. Stop when you come to the next colored page." The time required to complete each game was determined as was the number of dots completed correctly. Errors were not counted (e.g., missing a dot, passing through a dot incorrectly, passing through a dot more than once). The duration of the game and the number of dots completed correctly were used to calculate a dot rate for each of the 18 games (in dots per minute). These values were used to calculate the final baseline and multitasking dot rates (see below). As the study progressed, it became apparent that the control booklet contained more dot-to-dot games than necessary. To decrease the time spent by the children to complete the baseline measure, one game from each of the three sections was removed from each booklet.

Multitasking procedures. Each child was given an experimental booklet containing the same dot-to-dot games that he or she completed in the baseline task but in random order.[1] Games for which an accurate dot rate could not be determined during the baseline task (e.g., testing was interrupted, the children became

[1]Although a learning effect was anticipated by using the same games in the baseline and experimental conditions, the repetition was necessary to decrease the novelty of the task so that the child might be more inclined to direct his or her attention to the word categorization task.

Figure 2. Pictures illustrating the three categories to which the words belonged.

confused and stopped playing) were removed from the booklet. A total of 10 dot-to-dot games were removed from the booklets of 6 children. The booklet was opened to the first colored page with the following instructions: "You will play the same dot-to-dot games and respond to each word you hear as you did before but this time you will do them at the same time. You may turn the page and begin the dot-to-dot games when you hear the first word. If you hear static noise in the background, just ignore it. It is important that you do your best on the categorization task while you play the dot-to-dot games. If you make a mistake on a dot-to-dot game, you may continue or correct your mistake. I will tell you when to stop." Although it is not possible to know with any certainty that the children adhered to the instructions and directed their attention accordingly, the children indicated that they understood the instructions before beginning the task.

The order of word lists and conditions was counterbalanced across children to account for the possibility that one or more lists were especially easy or difficult. Each SNR and word list was presented only once to each child. Dot rate (in dots per minute) was calculated for each multitasking condition by determining the duration of the condition and the number of dots that were completed correctly in that time. Typically, the children were able to complete two to three games in each condition. Duration was provided by the laboratory software in minutes and seconds. A unique baseline dot rate was calculated for each condition by averaging the dot rates for the same games played in the baseline condition. For example, if a child completed games 2 and 7 in a particular multitasking condition, the dot rates for the same games in the baseline condition were averaged and served as the baseline dot rate.

RESULTS

The children's results were averaged for each group and listening condition and were then subjected to statistical analyses. Recall that (a) word categorization was expected to remain unchanged in each of the multitasking conditions relative to baseline, (b) dot rate was expected to decrease in the quiet multitasking condition, and (c) dot rate was expected to decrease further in the noise conditions. Also, the dot rates of the children with minimal HL were expected to be significantly slower than those of the NH children. Separate analyses were conducted to first determine the effect of multitasking on the dependent variables (word categorization and dot rate). Then the effects of listening condition and hearing status on multitasking were determined. For the first analyses, a series of *t* tests was conducted comparing the experimental and baseline measures. In the second analyses, the experimental measures alone were subjected to a multivariate analysis of variance (MANOVA).

Performance Relative to Baseline

Table 2 shows the average dot rate for each baseline and multitasking condition (in dots per minute) by group. Values in parentheses are standard error. Note that because the baseline dot rates were based on the same dot-to-dot games that were played in each multitasking condition, three baseline measures were obtained. Dot rates that differed significantly from baseline are indicated by asterisks. These results show remarkable similarity between the performance of each group in each condition. On average, both groups of children completed 49–50 dots/min in the baseline conditions and 42–43 dots/min in the experimental conditions. Overall, dot rate decreased in several multitasking conditions, suggesting that performance on this type of task may be sensitive to changes in cognitive demands. Paired-samples *t* tests confirmed that the dot rates of both groups decreased significantly

Table 2. Average baseline and experimental dot rates (dots per minute) for each multitasking condition for the NH children and the children with minimal HL. Values in parentheses are standard error. Numbers in italics are the result of paired-samples *t* tests (*t, p,* and Cohen's *d*). Note that the same games were played in each listening condition and that the baseline dot rates were not obtained in noise.

		Listening condition		
		Quiet	*+6 dB SNR*	*0 dB SNR*
NH	Baseline rate	52 (4)	46 (4)	48 (3)
	Experiment rate	44 (4)	42 (5)	41 (4)
	t	*4.349*	*1.519*	*3.101*
	p	*0.001**	*0.16*	*0.011**
	Cohen's *d*	*0.50*		*0.54*
HL	Baseline rate	50 (6)	49 (5)	50 (5)
	Experiment rate	45 (6)	42 (7)	41 (5)
	t	*2.244*	*3.670*	*2.994*
	p	*0.052*	*0.005**	*0.015**
	Cohen's *d*		*0.18*	*0.36*

*Significantly different from baseline as indicated by paired-samples *t* test ($p \leq 0.017$, Bonferroni adjustment).

from baseline ($p < 0.017$, Bonferroni adjustment) for at least two of the three multitasking conditions (quiet and 0 dB SNR for the NH children and +6 and 0 dB SNR for the children with HL). These results suggest that the children's performance on the dot-to-dot task was reduced when it was paired with the word categorization task. Also, both groups appeared to respond similarly to multitasking at 0 dB SNR.

Although the average dot rates were similar across groups, it is possible that dot rate was related to the configuration of HL. For example, the children with unilateral HL may have performed more poorly than the children with mild HL. Figure 3 shows the individual dot rates for each of the 10 children with minimal HL in each of the three listening conditions. Higher values indicate faster dot rates. The data for each child is plotted from left to right in the order that they are listed in Table 1; that is, in order of mild, high-frequency, and unilateral losses. The shaded areas indicate the minimum and maximum dot rates that were achieved by the NH children. Although the dot rates of 4 children with HL fell outside the range of those of the NH children, only 2 of the children (#7 and #8) completed the games at a slower rate in quiet and 0 dB SNR. One child (#7) had a bilateral high-frequency HL and the other (#8) had a unilateral high-frequency HL. Incidentally, these children also demonstrated the slowest dot rates in the baseline conditions. These data suggest that there is no apparent relationship between performance and configuration of HL and supports the conventional grouping of these children into a single category of minimal HL.

Table 3 shows the average word categorization for the baseline and multitasking conditions (in percentage correct) for each group. Values in parentheses are standard error. Note that only one baseline performance was necessary for this condition. For statistical analyses, the categorization scores were arcsine transformed to normalize the nonlinear distribution of scores, making them additive and comparable (Studebaker, 1985). Categorization performance that differed significantly from baseline is indicated by asterisks. All children achieved a baseline score of 100% on the word categorization task except for 1 NH child who had a score of 89% (one incorrect response). Paired-samples *t* tests were conducted ($p < 0.017$, Bonferroni adjustment) to compare performance in each multitasking condition to baseline. For the NH children, categorization remained high in each multitasking condition. For the children with minimal HL, however, performance dropped significantly from baseline in quiet and in both of the SNR conditions, although the difference was not large (~6%). These results suggest that the children with minimal HL experienced more difficulty multitasking in noise than did the NH children.

Figure 3. Dot rate for each child with minimal HL. The parameter is listening condition. The shaded areas represent the minimum and maximum dot rates for the children with NH in each of the listening conditions. The data points are listed for each child with HL in the order they are listed in Table 1.

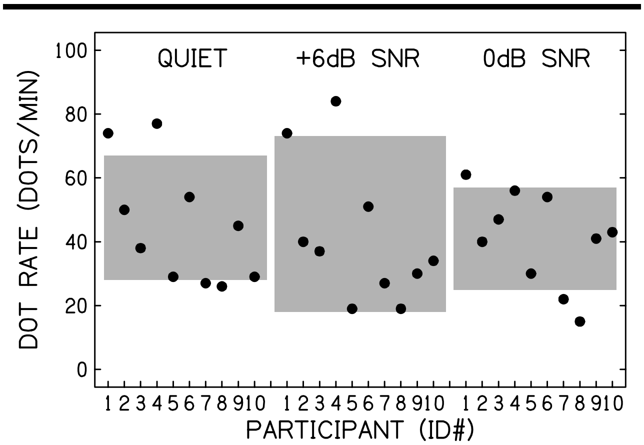


Table 3. Average word categorization (percentage correct) for the baseline and multitasking conditions for the NH children and the children with minimal HL. Values in parentheses are standard error. Numbers in italics are the result of paired-samples *t* tests (*t, p,* and Cohen's *d*).

	Baseline	*Listening condition*		
	Quiet	*Quiet*	*+6 dB SNR*	*0 dB SNR*
NH	99 (1)	100 (0)	97 (1)	99 (1)
	t	*–1.027*	*2.099*	*0.902*
	p	*0.338*	*0.062*	*0.902*
HL	100 (0)	97 (1)	94 (2)	94 (2)
	t	*2.355*	*4.039*	*3.337*
	p	*0.043*	*0.003**	*0.009**
	Cohen's *d*		*2.12*	*2.12*

*Significantly different from baseline as indicated by paired-samples *t* test ($p \leq 0.017$, Bonferroni adjustment).

Multitasking

To examine directly the effect of listening condition and hearing status on multitasking, a MANOVA with two independent variables (dot rate and word categorization) was performed with group (NH, HL) as the between-subjects factor and listening condition (quiet, +6 dB SNR, 0 dB SNR) as the within-subjects factor. Note that the baseline conditions were not included in these analyses. For dot rate, the analyses revealed no significant main effect for group, $F(1, 19) = 0.307$, $p = 0.586$, or listening condition, $F(2, 38) = 0.128$, $p = 0.880$, and no Group × Condition interaction, $F(2, 38) = 1.132$, $p = 0.333$. For word categorization, the analyses revealed a significant main effect for group, $F(1, 19) = 5.926$, $p = 0.025$, $\eta_p^2 = 0.238$, and condition, $F(2, 38) = 5.939$, $p = 0.006$, $\eta_p^2 = 0.238$, but no Group × Condition interaction, $F(2, 38) = 0.314$, $p = 0.733$. These results indicate that dot rate was affected similarly in each of the listening conditions for both groups despite the apparent difficulty that was imposed by the word categorization task on the children with HL. That is, the expected effects of listening condition and hearing status on the secondary task performance (dot rate) were not observed even though the primary task performance (categorization) of the children with minimal HL was significantly below that of the NH children.

DISCUSSION

The purpose of the present study was to examine the effect of minimal HL on multitasking in quiet and in noise. Using a dual-task paradigm, multitasking was evaluated relative to baseline measures as well as in three listening conditions in NH children and in children with minimal HL. Overall, the results suggest that the children's ability to complete simple dot-to-dot games slowed when they were asked to continue playing the games while responding to the word categorization task. When multitasking was conducted in a background of noise, the children in both groups continued to complete the dot-to-dot games at the same rate despite the difficulty that the children with minimal HL experienced with the word categorization task (i.e., a 6% decrease in performance). These results are nearly identical to those of the two previous studies in NH children and children with HL (Hicks & Tharpe, 2002; Stelmachowicz, et al., 2007). In both studies, secondary task performance decreased from baseline in the multitasking conditions. However, the anticipated reductions in secondary task performance (reaction time and digit recall, respectively) were not observed as the primary word recognition task became more difficult (variations in noise and bandwidth, respectively). Instead, performance on the word recognition task differed across groups and varied with listening condition.

Taken together, these results suggest that children in general do not respond to a difficult listening task by drawing resources from another task to compensate. Adults, on the other hand, have been shown to reduce their attention to a secondary task in order to accommodate the difficulty of a primary task. For example, Downs and Crum (1978) reported slower reaction times to a probe light when learning in noise relative to learning in quiet. In a later study, Downs (1982) reported a significant difference between the reaction times of adults who were attempting to perceive speech with and without the benefit of amplification. As one might predict, reaction time was slower in the unaided condition. Rakerd et al. (1996) reported significantly poorer digital recall during multitasking for a listening task that was presented in a background of speech compared to a background of noise. Finally, Rossiter et al. (2006) reported a significant increase in reaction time to a probe light as the primary task increased in difficulty (from reading aloud to word categorization). The results of each of these studies suggest that, unlike children, adults are able to reallocate their cognitive resources as they attend to different speech tasks.

Two possible interpretations may be made from the results of the present study. First, recall that the SNR conditions were chosen to increase the difficulty of the task without interfering greatly with perception. Assuming that this occurred, these results suggest that the children with minimal HL placed more resources in the dot-to-dot games, possibly because it was the easier of the two tasks. If so, it would suggest that children might not approach multitasking situations as adults do. That is, adults may allocate more resources to a difficult task simply because they were told to do so, whereas children may allocate their resources to tasks in which they are more successful despite instructions to the contrary. The similarity in dot rate between the two groups of children supports this interpretation. Although the word categorization of the children with minimal HL was poorer than that of the NH children, the children with minimal HL demonstrated a dot rate that was comparable to that of their NH peers.

An alternative interpretation is that the children with minimal HL thought that they were performing maximally on the word categorization task in the SNR conditions. Listeners with HL are often unaware of the messages that they perceive incorrectly. In the context of this study, the children may have attended to the word categorization as instructed without realizing the errors they were making. Had the children been made aware of their performance, greater decreases in secondary task performance might have been observed; however, there is no guarantee that primary task performance would have improved. This interpretation suggests that if children are not aware of their poor speech perception, they may not recognize the need to reallocate their recourses accordingly.

LIMITATIONS OF THE STUDY

It is important to recognize the limitations of this study, many of which are common to studies involving children with HL. First, the controlled conditions necessary to examine effects like multitasking and the influence of noise limit the generalization of the results because the test conditions are far from most naturalistic environments. Therefore, it is possible that the multitasking difficulties that these children experience in an actual classroom are more or less problematic than was demonstrated here. Second, and more important, children with HL are a highly heterogeneous population. In addition to the factors that contribute to the variability of all children (e.g., age, IQ, socioeconomic status), children with HL also vary in terms of the etiology of the HL; the degree and configuration of the HL; the age at which they were identified with HL and received intervention; the hearing aid make, model, and features prescribed to them; their mode of communication; the consistency with which they use their hearing aids or attend intervention programs; the support they receive from their parents and other family members; and their perceived communication handicap. These and other factors make it difficult to recruit a large homogenous group of children with HL for research. Although the performance of the small sample of children in the present study was consistent across configurations of HL and statistically different from that of the NH children, the results should be considered carefully and applied cautiously to the population of children with minimal HL.

IMPLICATIONS

Because the present study is the third such study to indicate that children, especially children with HL, appear to allocate their resources away from listening tasks, teachers and school administrators may wish to add to their understanding the potential difficulties that children may experience when multitasking in the classroom. Although it is not yet possible to determine a child's ability to multitask through standardized testing, accommodations can be made to reduce the frequency of multitasking. Those accommodations may include more time to complete assignments, providing a note taker for older students so that they may direct more attention to the instructor, and separating class assignments from instruction so that the child does not have to listen and work at the same time. To improve SNRs in the classroom, the installation of acoustic tiles and carpeting, insulated windows, and quieter ventilation systems will reduce the overall noise level. These accommodations are especially important if the classroom is located near external sources of noise such as a playground, gymnasium, or busy street. Optimally, every child with HL should use an FM system in the classroom. This device is designed to transmit the teacher's voice via a lapel microphone directly to the child's hearing aid. In this way, the child receives a consistent, low-noise signal that allows him or her to better attend to the teacher.

DIRECTIONS FOR FUTURE RESEARCH

These results provide a number of topics for future research. First, it would be interesting to replicate this study using a multi-talker competitor rather than broadband noise to determine the effect of a distracter that contains semantic content. It would also be wise to examine directly the differences in multitasking between children and adults as well as the development of multitasking skills should differences be found. Also, multitasking as it relates to the degree and configuration of HL should be examined. It would also be helpful to understand how the difficulty of a secondary task affects a child's ability to process speech. Finally, the degree to which children can successfully attend to two tasks in a noisy environment may be related to the level at which they find noise acceptable (termed: acceptable noise level [ANL]). Considerable data have been gathered showing that ANL is not related to a listener's age, degree of HL, or ability to perceive speech, but it has been correlated with hearing aid acceptance and use (Franklin, Thelin, Nabelek, & Burchfield, 2006; Freyaldenhoven, Smiley, Muenchen, & Konrad, 2006; Freyaldenhoven, Plyler, Thelin, & Hedrick, 2007; Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). It is possible that the deleterious effects of noise may become more apparent while attempting to multitask and that a child's ability to multitask may be predicted by his or her ANL.

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REFERENCES

American National Standards Institute. (1999). *Maximum permissible ambient noise levels for audiometric test rooms* (ANSI S3.1 1-1999). New York: Author.

Bess, F. H. (1985). The minimally hearing-impaired child. *Ear and Hearing, 6,* 43–47.

Bess, F. H., Dodd-Murphy, J., & Parker, R. A. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear and Hearing, 19,* 339–354.

Blaire, J. C., Peterson, M. E., & Viehweg, S. H. (1985). The effects of mild sensorineural hearing loss on academic performance of young school-age children. *The Volta Review,February/March,* 87–90.

Crandell, C. C. (1993). Speech recognition in noise by children with minimal degrees of sensorineural hearing loss. *Ear and Hearing, 14,* 210–216.

Crandell, C. C., & Smaldino, J. J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech, and Hearing Services in Schools, 31,* 362–370.

Davis, J. M., Elfenbein, J., Schum, R., & Bentler, R. A. (1986). Effects of mild and moderate hearing impairments on language, educational, and psychosocial behavior of children. *Journal of Speech and Hearing Disorders, 51,* 53–62.

Davis, J. M., Shepard, N. T., Stelmachowicz, P. G., & Gorga, M. P. (1981). Characteristics of hearing-impaired children in the public schools: Part II—Psychoeducational data. *Journal of Speech and Hearing Disorders, 46,* 130–137.

Downs, D. W. (1982). Effects of hearing use on speech discrimination and listening effort. *Journal of Speech and Hearing Disorders, 47,* 189–193.

Downs, D. W., & Crum, M. A. (1978). Processing demands during auditory learning under degraded listening conditions. *Journal of Speech and Hearing Research, 21,* 702–714.

Feuerstein, J. F. (1992). Monaural versus binaural hearing: Ease of listening, word recognition, and attentional effort. *Ear and Hearing, 13,* 80–86.

Franklin, C. A., Jr., Thelin, J. W., Nabelek, A. K., & Burchfield, S. B. (2006). The effect of speech presentation level on acceptance of background noise in listeners with normal hearing. *Journal of the American Academy of Audiology, 17,* 141–146.

Freyaldenhoven, M. C., Plyler, P. N., Thelin, J. W., & Hedrick, M. S. (2007). The effects of speech presentation level on acceptance of noise in listeners with normal and impaired hearing. *Journal of Speech, Language, and Hearing Research, 50,* 878–885.

Freyaldenhoven, M. C., Smiley, D. F., Muenchen, R. A., & Konrad, T. N. (2006). Acceptable noise level: Reliability measures and comparison to preference for background sounds. *Journal of the American Academy of Audiology, 17,* 640–648.

Hicks, C. B., & Tharpe, A. M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. *Journal of Speech, Language, and Hearing Research, 45,* 573–584.

Kenworthy, O. T., Klee, T., & Tharpe, A. M. (1990). Speech recognition ability of children with unilateral sensorineural hearing loss as a function of amplification, speech stimuli and listening condition. *Ear and Hearing, 11,* 264–270.

Kochkin, S., Luxford, W., Northern, J. L., Mason, P., & Tharpe, A. M. (2007). MarkeTrak VII: Are one million dependents with hearing loss in America being left behind? *The Hearing Review, 14,* 10–36.

Moe, A. H., Hopkins, C. J., & Rush, R. T. (1982). *The vocabulary of first grade children*. Springfield, IL: Thomas.

Nabelek, A. K., Freyaldenhoven, M. C., Tampas, J. W., Burchfield, S. B., & Muenchen, R. A. (2006). Acceptable noise level as a predictor of hearing aid use. *Journal of the American Academy of Audiology, 17,* 626–639.

Nozza, R. J., Bluestone, C. D., Kardatzke, D., & Bachman, R. N. (1992). Toward the validation of aural acoustic immittance measures for diagnosis of middle ear effusion in children. *Ear and Hearing, 13,* 442–453.

Nozza, R. J., Bluestone, C. D., Kardatzke, D., & Bachman, R. N. (1994). Identification of middle ear effusion by aural acoustic admittance and otoscopy. *Ear and Hearing, 15,* 310–323.

Rakerd, B., Seitz, P. F., & Whearty, M. (1996). Assessing the cognitive demands of speech listening for people with hearing losses. *Ear and Hearing, 17,* 97–106.

Rossiter, S., Stevens, C., & Walker, G. (2006). Tinnitus and its effect on working memory and attention. *Journal of Speech, Language, and Hearing Research, 49,* 150–160.

Shepard, N. T., Davis, J. M., Gorga, M. P., & Stelmachowicz, P. G. (1981). Characteristics of hearing-impaired children in the public schools: Part I—Demographic data. *Journal of Speech and Hearing Disorders, 46,* 123–129.

Stelmachowicz, P. G., Lewis, D. E., Choi, S., & Hoover, B. (2007). Effect of stimulus bandwidth on auditory skills in normal-hearing and hearing-impaired children. *Ear and Hearing, 28,* 483–494.

Studebaker, G. A. (1985). A "rationalized" arcsine transform. *Journal of Speech and Hearing Research, 28,* 455–462.

Tharpe, A. M., & Bess, F. H. (1999). Minimal, progressive, and fluctuating hearing losses in children. Characteristics, identification, and management. *Pediatric Clinics of North America, 46,* 65–78.

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APPENDIX. WORD LISTS USED IN THE BASELINE AND EXPERIMENTAL CATEGORIZATION TASKS.

Baseline	*List 1*	*List 2*	*List 3*
Deer	Beaver	Bear	Bat
Goose	Bird	Cat	Chipmunk
Turtle	Cow	Dolphin	Giraffe
Bread	Dog	Donkey	Horse
Cheese	Duck	Fox	Kitten
Jelly	Goat	Frog	Pig
Boy	Monkey	Lion	Raccoon
Girlfriend	Penguin	Owl	Squirrel
Grandma	Skunk	Pony	Tiger
	Walrus	Rabbit	Wolf
	Bacon	Brownie	Apple
	Cream	Candy	Cake
	Donut	Carrot	Catsup
	Fudge	Hotdog	Cereal
	Mushroom	Olive	Cookie
	Peanut	Pancake	Cracker
	Sandwich	Pizza	Jello
	Spinach	Popcorn	Lettuce
	Toast	Pumpkin	Potato
	Tomato	Sugar	Pudding
	Baby	Aunt	Boyfriend
	Brother	Chief	Burglar
	Captain	Cousin	Dentist
	Cowboy	Dad	Friend
	Girl	Daughter	Indian
	Grandpa	Father	Man
	Lady	Husband	Nurse
	Neighbor	Mom	Sister
	Princess	Soldier	Teacher
	Shepherd	Woman	Uncle

Note. Each list contains equal numbers of words referring to people, food, and animals.