THE EFFECT OF BACKGROUND NOISE ON MULTITASKING

By

Jaclyn Moor

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As members of the Audiology Doctoral Project (ADP) Committee, we certify that we have read the ADP prepared by Jaclyn Moor, titled The Effect of Background Noise on Multitasking, and recommend that it be accepted as fulfilling the ADP requirement for the Degree of Doctor of Audiology.

____ Date: 04/28/2017
Nicole Marrone, Ph.D., CCC-A

____ Date: 04/28/2017
Linda Norrix, Ph.D., CCC-A

____ Date: 04/28/2017
Brad Story, Ph.D.

____ Date: 04/28/2017
Jamie Edgin, Ph.D.

Final approval and acceptance of this ADP is contingent upon the candidate's submission of the final copies of the ADP to the Graduate College.

I hereby certify that I have read this ADP prepared under my direction and recommend that it be accepted as fulfilling the ADP requirement.

____ Date: 04/28/2017
ADP Director: Nicole Marrone, Ph.D., CCC-A

STATEMENT BY AUTHOR

SIGNED: Jaclyn Moor

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ABSTRACT

Multitasking in background noise may involve greater cognitive processing demands than multitasking in quiet due to an increase in perceptual demands (Rabbitt, 1968; Pichora-Fuller & Schneider, 2000). This study investigated the effect of background noise in the listening environment on the ability of young adults with normal hearing and older adults with sensorineural hearing loss to perceive speech while performing a secondary task. A dual task paradigm, which included word recognition and visual serial recall, was used to examine ability to divide limited processing resources between two tasks. The number of digits to be recalled was varied in order to test the hypothesis that background noise would degrade multitasking abilities to a greater degree than in quiet for more difficult tasks. Participants included 37 native English speakers between 19-25 years of age with pure-tone thresholds better than or equal to 20 dB HL and 10 English speakers between 58-85 years of age with pure-tone thresholds greater than or equal to 25 dB HL in both ears. The results showed that background noise can have negative effects on the ability to multitask for both younger adults with normal hearing and older adults with hearing loss; however, this effect was greater for the older adults with hearing loss, especially when task demands were increased.

INTRODUCTION

Multitasking is a common experience in everyday life and often involves communication. The ability to understand speech while performing simultaneous cognitive tasks is essential for communication and social interaction. Imagine a cocktail party where two people are talking with the general noise of the party in the background. One person recites his or her phone number in the middle of a conversation and the other person must remember that number while also paying attention to the rest of the conversation. In addition, this communicative interaction is occurring in the presence of background noise, which degrades the speech signal and increases listening effort, defined by McGarrigle et al. (2014) as "the mental exertion required to attend to, and understand, an auditory message" (p. 434). It is reasonable to assume that invoking attentional and cognitive resources will facilitate speech understanding as listening environments become challenging. While increased listening effort, which includes attentional and cognitive resources, might allow the listener to recognize speech, it is also possible that the noise would result in decreased speech recognition. Even in cases where speech recognition is not degraded, the addition of background noise or speech babble may interfere with performance on other activities, such as memory for speech (Rabbitt, 1968; McCoy, Tun, Colangelo, Wingfield et al., 2006) or performance on secondary tasks (Broadbent, 1958; Feuerstein, 1992; Fraser, Gagné, Alepins & Dubois, 2007; Bourland-Hicks & Tharpe, 2002; Gosselin & Gagné, 2010).

There are a number of ways to assess the availability of cognitive processing resources and effortful listening, but one of the most common is a dual-task paradigm in which subjects perform two tasks simultaneously. A dual-task paradigm is designed based on theories of attentional limitations or cognitive load (Broadbent, 1958;

Kahneman, 1973; Pashler, 1994; Pashler & Johnston, 1998). Cognitive load refers to the total amount of processing resources and mental effort used to perform a task. During a dual-task experiment, the cognitive load is intentionally made high by requiring simultaneous processing of complex information, necessitating use of working memory and executive functions (Paas, Renkl, & Sweller, 2003). The greater the cognitive load, the more likely that cognitive resources, such as working memory capacity, will be exceeded due to performance on a secondary task. In such an experimental design, behavioral performance declines on the secondary task are interpreted as the "cost" of the dual-task (Pashler, 1994).

The dual-task paradigm provides a means of testing age-related changes in complex cognition and communication (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). The effects of cognitive load on adult speech production and motor control have been studied extensively, with different effects for younger compared to older adults (Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Maylor & Wing, 1996; Maylor, Allison, & Wing, 2001; Bunton & Keintz, 2008; Keintz, Bunton & Hoit, 2007). For example, Kemper, Herman & Lian (2003) obtained language samples from 77 younger and 91 older adults while performing simultaneous tasks. Language samples were obtained by asking participants to answer a list of questions while walking, completing a simple and a complex finger tapping task, ignoring concurrent speech, and ignoring concurrent noise. The authors found that the younger and older adults both adapted successfully to the dual task conditions but used different strategies. The younger adults showed no change in speech rate but sentences were shorter in length and less grammatically complex. In contrast, the older adults spoke more slowly. In the dual task condition, only the complex tapping task was more disruptive for the older adults compared to the younger adults. The authors suggested that older adults may experience greater costs than younger adults in challenging dual tasks.

Based on the Kemper et al. (2003) study it is reasonable to predict that sensory and cognitive processing in older adults with hearing loss might be differentially disrupted compared to younger adults with normal hearing when the dual task is performed in background noise. One task that is challenging for adults with hearing loss is word recognition in noise (Dubno, Dirks, & Morgan, 1984; Abel, Krever, & Alberti, 1990; Helfer & Wilbur, 1990). Dual task experiments that manipulate perceptual demands by using word recognition in background noise could potentially assess real-world hearing and cognitive abilities in older adults.

To date, there has been minimal research using dual tasks involving word recognition with background noise in adults with hearing loss; however, this topic has been explored in children with normal hearing. The effects of perceptual and working memory capacity demands on children's ability to recognize words in noise and perform a simultaneous visual serial recall task of 3- or 5-digit number strings was examined by Choi, Lotto, Lewis, Hoover, and Stelmachowicz (2008). Each child was randomly assigned to one of two task priority instructions: group 1 was instructed to focus their primary attention on recognizing the words, and group 2 was instructed to focus their primary attention on recalling the digits. It was expected that the group focusing on the recognition task would experience a decrement in the digit recall task and that the group focusing on recall would experience a decrement in word recognition. The authors found only a decrease for serial recall (the secondary task) regardless of task priority and speculated that children may not have developed the ability to control top-down attentional processes. Further, they suggested that adults would have the ability to control top-down processes and therefore would be able to control task priority. However, to our knowledge, this hypothesis has yet to be empirically tested.

In a similar experimental paradigm, Howard, Munro, and Plack (2010) assessed perceptual demands in children as background noise increased, with levels similar to that of a classroom environment. The dual-task included word recognition and 5-digit visual serial recall. The word recognition task was presented in quiet and multi-talker babble at various signal-to-noise ratios (SNRs). The children were instructed to focus their attention on the word recognition task, and were given positive feedback for words repeated correctly. The results showed that in the dual task, children were able to maintain their performance in the listening task but performance on digit recall declined. The authors concluded that greater listening effort was required as background noise levels became less favorable. This finding was interpreted as consistent with the *effortfulness hypothesis* which, McCoy et al. (2005) describe as "…the notion that the extra effort that a hearing-impaired listener must expend to achieve this perceptual success may come at the cost of processing resources that might otherwise be available for encoding the speech content in memory" (p. 23).

Although it appears from the above experiments that children can maintain performance for the word recognition task in noise when in a dual task paradigm, their performance on a simultaneous memory task declines. It is currently unknown how older adults with hearing loss will perform within similar dual task conditions in background noise. In addition to the effects of aging on cognition (Verhaeghen et al., 2003), poor hearing acuity may cause further decrements to dual task performance and may impact both the word recognition and serial recall tasks. Some evidence for this comes from a study by McCoy et al. (2005) who examined recall ability in older adults (ages 66-81 years) with and without hearing loss. McCoy et al. (2005) asked participants to listen to sixteen recorded sentences of 15 words each. When the word list was randomly paused, subjects were asked to recall the last 3 words. The authors found that both groups had nearly-perfect recall of the final word. However, the adults with hearing loss had more difficulty recalling the 1st and 2nd words in the 3-word set compared to adults with normal hearing. They suggested that the hearing loss group spent greater effort on hearing the words, which in turn left fewer resources for processing and rehearsing the words. Overall, this study supports the idea that effortful listening is increased for individuals with hearing loss, which may ultimately affect their ability to perform two simultaneous tasks.

The purpose of the present study was to examine the effects of perceptual and capacity demands in young adults with normal hearing (Experiments I and II) and older adults with mild to moderately-severe sensorineural hearing loss (Experiment III) using a dual-task paradigm modeled after the studies by Choi et al. (2008) and Howard et al. (2010). The dual-task paradigm consisted of visual serial recall and word recognition tasks. Visual serial recall was chosen because mental rehearsal of digits is known to interfere with the working memory involved in recognizing and repeating words (Baddeley, 2003). Several presentation levels of background multi-talker babble were used to experimentally vary perceptual demands during word recognition. In addition, different digit string sizes were used to experimentally vary capacity demands during visual serial recall.

GENERAL METHODS

All participants provided written informed consent to participate in this study, following a protocol approved by the Institutional Review Board at The University of Arizona. Eligibility criteria included English as a first language and no history of neurological trauma or attention/learning disabilities. After the participants completed a short demographics questionnaire, otoscopy and pure-tone audiometry were performed. Pure-tone air and bone conduction thresholds and speech reception thresholds were measured using standard clinical procedures (modified Hughson-Westlake procedures at octave frequencies) with an audiometer (Otometrics Aurical). The experiment was conducted in a double-walled sound booth (Dimensions: 12 feet x 12 feet x 12 feet; Industrial Acoustics Company, Inc.) and all stimuli was presented through a single loudspeaker located at 0° azimuth at a distance of 1 meter from the listener inside the booth. The computer controlling the experiment was located outside the booth. The equipment was calibrated using a Larson-Davis System 824 sound level meter. The participants were seated in a chair positioned in the center of the sound booth with a small table holding a monitor display (iMo S10). Each participant completed the experimental tasks that included visual serial digit recall (single-task in quiet), word recognition (single-task in quiet), and simultaneous performance of both tasks (dual-task in quiet and in noise), in this exact order. Each participant was required to attend one session and was given $10 per hour of participation or received class credit for participating.

Stimuli and Procedures

Visual Serial Digit Recall (Single Task in Quiet)

Random sets of digits (digits 1 to 9) were generated by a computer, with replacement. Digit strings with more than 3 multiples of the same number were excluded. None of the strings were entirely ascending or descending. The digit strings were displayed on a monitor (iMo S10) for 3 seconds at 72-point font, with a single space between each digit. The digit strings were presented in the center of the monitor using a timed PowerPoint slideshow (Microsoft Office 2010). The participants were instructed to remember the numbers that would be displayed on the screen. On each trial, the participants were prompted with an audio recording of the instruction, “Look at the numbers,” along with a visual aid. The digits were then displayed on the monitor for 3 seconds. After 20 seconds of silence participants were prompted to recall the numbers with an audio recording of the instruction, “Say the numbers.” Each subject participated in 5 trials. The number strings were scored with each digit as an individual item that had to be reported in correct serial position.

Word Recognition (Single Task in Quiet)

To establish each subject’s optimal performance with minimal perceptual demand, a single task word recognition assessment was conducted in quiet using 20 words from the pre-recorded NU-6 Lists. These lists are comprised of monosyllabic words such as “date”, “dog”, “live”, “have”, and “gas” recorded by a female speaker in English with a general American dialect. Each word has a carrier phrase (“Say the word…”). Participants were instructed to listen to each word and immediately repeat it aloud. They were also encouraged to guess if unable to recognize the word. A visual aid appeared on the computer screen, which prompted the participants to listen to the words. Words were scored by phoneme, with 3 phonemes in each word, for a total score of 60 possible points. A change in phoneme was only marked incorrect if the meaning of the word changed, thus, different pronunciations of the same word (/dɒg/ or /dɔːg/ for the word “dog”) were considered correct.

Dual-Task

For the dual-task, the participants were asked to simultaneously complete the visual serial recall and word recognition task. First, the participants were prompted with “Look at the numbers,” along with a visual aid. A unique number string was presented on the portable screen while, simultaneously, a set of 5 words was presented through the loudspeaker, for 20 seconds. The participants were instructed to remember the digit string, in the exact order, while they repeated the words aloud after each word presentation. At the end of the trial they were prompted with “Say the numbers,” requiring them to recall the digit string. Stimuli for the word recognition task were taken from the Words In Noise (WIN) test (Wilson & McArdle, 2007; Wilson, 2003). The WIN stimuli include the same monosyllabic words from the NU-6 lists that are digitally combined with multi-talker babble (six talkers, 3 female and 3 male) at multiple SNRs. The multi-talker babble begins between 1 to 2 seconds before the first word of a five-word set and ends 1 to 2 seconds after the end of the fifth word. Each subject was presented two practice sets of WIN stimuli. Following the practice trials, sets of 5 words, with each word in the set at the same SNR, were presented. The experimental listening block included three different SNR conditions and a quiet condition, with four sets of 5 words presented for each condition. The sets were presented in a random order. Therefore, the dual task included a total of 18 word sets consisting of 2 practice sets and 16 test sets (4 sets in quiet, 4 sets at each of three different SNRs). Subject responses for both word recognition and serial recall were scored in the same manner as the single tasks in quiet.

General Data Analysis: Difference Scores

All raw scores were initially converted to percentages. To determine the cost of the dual-task on performance, we then calculated a difference score for both serial recall and word recognition for the quiet conditions: dual-task percentage in quiet – single task percentage in quiet. This is referred to as the Quiet condition and reflects only the cognitive cost of the dual task. To determine the combined effect of the dual task and noise on performance, we also calculated the difference between each participant's performance (in percentage) at each SNR in the dual task and performance for the single task in quiet. This resulted in a separate difference score for each of the three SNR conditions used in each experiment. Thus, for both recall and recognition, three difference scores, one for each SNR, were calculated for each participant (SNR1, SNR2, SNR3). Repeated measures analysis of variance (RMANOVA) were performed using SPSS software on the four difference scores calculated (Quiet, SNR1, SNR2, SNR3). Post-hoc comparisons were used to compare the Quiet condition with each noise condition. Because the difference score for each noise listening condition is calculated by subtracting the single task performance in quiet from the dual task performance for that condition, any differences between the Quiet difference score and noise difference scores reflect the effects of the noise on performance. One-tailed paired sample t-tests were used for these comparisons as it was expected that the addition of noise would always increase the difference between the single and dual task (i.e., the performance score for the dual task in noise minus the single task score in quiet would always be greater than the performance score for the dual task in quiet minus the single task score in quiet).

EXPERIMENT I

In Experiment 1, perceptual demands were manipulated by varying the levels of background noise during the dual task. Task instructions for the dual task (i.e., focus primary attention on recognizing the words or focus primary attention on recalling the digits) were also varied in an effort to determine whether performance in a dual task can be influenced merely by instructions to focus on one or the other of the tasks. Although children do not appear to have the ability to control attentional processes given a task priority instruction (Choi et al., 2008), adults may exhibit top-down attentional control. This is important to consider because if no instructions are provided, subjects may use either strategy resulting in variable performance.

Methods

Participants

Eighteen college students were recruited from the University of Arizona community. Of these, 10 identified as Caucasian, 4 as Asian, 3 as Hispanic, and 1 declined to identify. Each participant was between the ages of 19-26 years (15 female, 3 male) and had pure-tone thresholds (250-8000 Hz) better than or equal to 20 dB HL.

Stimuli and Procedures

The procedures and stimuli are as described in the general methods section. For the visual serial recall tasks, 5-digit serial strings were used. For the word recognition task, practice trials were presented at a +16 dB SNR. The SNRs for the experimental conditions were +8, +4, and 0 dB. These were selected based on pilot data that showed no ceiling or floor effects for these SNRs in this particular dual-task. Each listener was randomly assigned to a 20 or 40 dB sensation level (SL) group; that is, the presentation level of the speech was either 20 dB or 40 dB HL above each listener's speech reception threshold.

Instructional emphasis. During the dual task, the participants were randomly assigned one of two possible instructions. Those given an instructional emphasis on serial recall (n = 10) were asked to focus their attention on remembering the digit strings. The participants given an instructional emphasis on word recognition (n = 8) were asked to focus their attention on recognizing and repeating the words. Even though the participants were given an emphasis, they were still encouraged to perform both tasks to the best of their ability.

Results

Preliminary Dual Task Analysis

Our first analysis investigated the effect of sensation level on word recognition and serial recall. An RMANOVA, with listening condition (quiet, +8 dB, +4 dB, 0 dB) as the within subject factor and sensation level (20 and 40 dB) as the between group factor, was performed on the difference scores for each task emphasis group. The results indicated no significant main effects of sensation level and no significant interaction between sensation level and listening condition for word recognition or for serial recall (Table 1). Sensation level was therefore collapsed for all further analyses.

TABLE 1: Sensation Level Statistics

		Source	Sum of Squares	Df	Mean of Square	F	Significance
Serial Recall	Word Emphasis	Listening Condition	0.54	3 (18)	0.018	1.042	0.398
		Listening Condition x Sensation Level	0.063	3 (18)	0.021	1.223	0.330
		Sensation Level	0.009	1 (6)	0.009	0.249	0.635
	Recall Emphasis	Listening Condition	0.019	3 (24)	0.006	0.667	0.580
		Listening Condition x Sensation Level	0.036	3 (24)	0.012	1.271	0.307
		Sensation Level	0.014	1 (8)	0.014	0.327	0.583
Word Recognition	Word Emphasis	Listening Condition	0.714	3 (18)	0.238	26.657	0.000
		Listening Condition x Sensation Level	0.041	3 (18)	0.014	1.543	0.238
		Sensation Level	0.012	1 (6)	0.012	0.369	0.566
	Recall Emphasis	Listening Condition	0.902	3 (24)	0.301	58.635	0.000
		Listening Condition x Sensation Level	0.017	3 (24)	0.006	1.129	0.357
		Sensation Level	0.020	1 (8)	0.020	3.397	0.103

Instructional Emphasis and Perceptual Demands

Word recognition accuracy in quiet for the single task and dual task was near ceiling (>97.8%) for both the recall and word recognition emphasis groups (Table 2). Figure 1 (right panel) displays the difference scores for the word recognition task for participants with a word recognition emphasis (n=8) and participants with a serial recall emphasis (n=10) as a function of listening condition (quiet, +8, +4, 0 dB SNR). An RMANOVA with the within subject factor of listening condition and the between group factor of instructional emphasis showed a significant main effect of listening condition [F(3, 48) = 77.93, p<0.01]. Post hoc paired sample t-tests, using a Bonferroni corrected p-value of 0.0167, revealed that the mean difference score for the Quiet condition (M=0.01) was significantly smaller than the difference scores for each SNR condition (M=-0.11, -0.25, -0.42; for the +8, +4, and 0 dB conditions, respectively). The p-value for each comparison was <0.01. There was no significant effect of instructional emphasis [F(1, 16) = 0.07, p = 0.80] and no significant interaction between instructional emphasis and listening condition [F(3, 48) = 0.17, p = 0.84].

TABLE 2: Means and Standard Deviations for Normal Hearing Adults (5-digit recall)

				Quiet	8 dB SNR	4 dB SNR	0 dB SNR
Recall Emphasis	Word Recognition	Single Task	Mean	97.8%	85.8%	69.4%	55.3%
			SD	0.02	0.07	0.14	0.13
		Dual Task	Mean	98.8%	86.0%	73.7%	56.0%
			SD	0.01	0.06	0.09	0.10
	Serial Recall	Single Task	Mean	97.6%			
			SD	0.04			
		Dual Task	Mean	95.0%	89.5%	91.0%	89.0%
			SD	0.08	0.16	0.13	0.15
Word Rec Emphasis	Word Recognition	Single Task	Mean	98.5%	87.9%	69.8%	55.4%
			SD	0.01	0.05	0.18	0.13
		Dual Task	Mean	99.0%	88.3%	73.5%	59.4%
			SD	0.02	0.05	0.18	0.16
	Serial Recall	Single Task	Mean	100.0%			
			SD	0.00			
		Dual Task	Mean	85.6%	82.5%	87.5%	93.8%
			SD	0.13	0.16	0.20	0.07

For serial recall, the quiet conditions were associated with near-ceiling performance in the single task conditions (>97.6% accuracy). While accuracy remained high in the dual task for the subjects in the recall emphasis group in quiet (95%) the mean accuracy for the word recognition emphasis group in quiet was

85.6% (Table 2). However, individual performance for the recognition emphasis group was variable (SD of 0.13) and likely reflects a group of individuals with varying working memory capacity. Figure 1 (left panel) displays the difference scores obtained for serial recall. An RMANOVA, with the within subject factor of listening condition and the between group factor of instructional emphasis, revealed no significant effect of listening condition [F(3, 48) = 0.73, p = 0.50], no significant effect of instructional emphasis [F(1, 16) = 1.84, p = 0.19] and no interaction between listening condition and instructional emphasis [F(3, 48) = 1.28, p = 0.29].

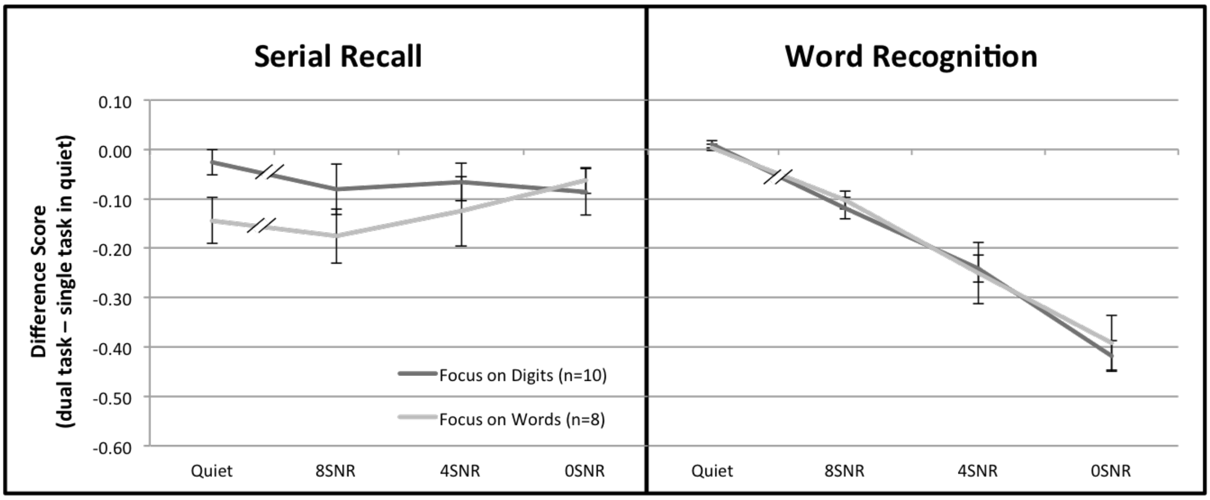

FIGURE 1: Normal Hearing Adults, 5-digit Recall with Instructional Emphasis

Discussion

Experiment I investigated the effects of manipulating SNR and the effects of instructional emphasis on dual task performance involving word recognition and visual serial recall in young adults with normal hearing. Instructional emphasis (focus on the digits or focus on the words) had no influence on digit recall or word recognition performance when noise was added to the dual task conditions. Although we predicted that the addition of noise would increase perceptual demands and decrease performance for the task that was de-emphasized, this did not appear to be the case. When the SNR decreased, subjects in the word recognition emphasis group performed similarly to the subjects in the serial recall emphasis group. It appears that, similar to what Choi et al. (2008) found for young children, adults were not able to use top-down attentional processes to control their performance in this dual-task.

For word recognition in quiet, the dual task appeared to have no impact on serial recall as the mean recall accuracy in the single task was similar to the mean recall accuracy in the dual task. When noise was added to the dual task, word recognition scores declined. This was an expected finding, as speech recognition in noise is known to be more challenging than in quiet (Wilson, 2003; Killion, Gudmundsen, Revit & Banerjee, 2004; Nilsson, Soli & Sullivan, 1994; Murohy, Craik, Li & Schneider, 2000). More importantly, the addition of noise had no significant impact on 5-digit recall in the dual task conditions. This finding is contrary to Howard et al. (2010), who showed decreased performance on a serial recall task during a dual task condition, for children, especially with increasing background noise levels. Other dual task experiments have also shown decreased performance for both tasks in a dual task paradigm compared to the same tasks in isolation (Fraser, Gagné, Alepins and Dubois, 2010). It is possible; however, that the 5-digit serial recall task was too easy for our young adult subjects whose memory span for digits is around 6-digits (Orsini, Grossi, Capitani, Laiacona, Papagno & Vallar, 1987).

EXPERIMENT II

The purpose of Experiment II was to investigate the effect of increased capacity demands (5 digit vs. 7 digit recall) on dual task performance in young adults. We hypothesized that, similar to the dual task that used 5-digit recall, subjects performing the dual task using 7-digit recall would have difficulty recognizing words in the presence of noise compared to in quiet. In addition, we hypothesized that the increased demands on working memory (7 digit recall) would result in a decrease in serial recall performance particularly in the most difficult SNR conditions.

Methods

Participants

Nineteen college students were recruited from the University of Arizona community. Of these participants, 11 identified as Caucasian, 1 as Asian, 3 as Hispanic, 2 as African American, and 2 declined to identify. Each of the participants was between the ages of 19-26 years (17 female, 2 male).

Stimuli and Procedures

The stimuli and procedures are described in the general methods section. For the visual serial recall tasks, 7-digit serial strings were used. For the word recognition task, practice trials were presented at a +16 dB SNR. The SNRs for the experimental conditions were +8, +4, and 0 dB. The presentation level of the speech was fixed at 20 dB SL above each participant's speech recognition threshold (on average, 13 dB HL).

Results

Mean accuracy scores for word recognition and serial recall are provided in Table 3. In quiet, the mean 7-digit serial recall accuracy for the single task was 94.6%. Performance dropped to 80.1% in the dual task condition. However, the standard deviation was large (SD=0.17) indicating variability in subject's ability to perform the 7-digit dual task. In contrast, word recognition in quiet was near-ceiling for both the single task (M=98.2%) and the dual task (M=98.8%). FIGURE 2 illustrates difference scores for serial recall and word recognition as a function of listening condition. One-way within subjects RMANOVAs were conducted to compare the effects of listening condition (quiet, +8, +4, 0 dB) on serial recall performance and on word recognition performance. For serial recall, there was a significant main effect of listening condition [($F(3, 54) = 2.714$, $p = 0.05$]. Post hoc paired sample t-tests, using a Bonferroni corrected p-value of 0.0167, revealed only a significant difference between the Quiet (M=-0.15) and 0 dB SNR condition (M=-0.26, $p = 0.016$). For word recognition, there was a significant main effect of listening condition [($F(3, 54) = 78.702$, $p < 0.01$]. Post hoc paired sample t-tests, using a Bonferroni corrected p-value of 0.0167, revealed that each SNR listening condition (M= -0.08, -0.27, -0.38; for the +8, +4, and 0 dB SNR conditions, respectively) was significantly different from the Quiet condition (M=0.01). The p-value for each comparison was <0.01. Thus, in the dual task, the addition of noise significantly decreased word recognition performance compared to in quiet.

TABLE 3: Means and Standard Deviations for Normal Hearing Adults (7-digit recall)

			Quiet	8 dB SNR	4 dB SNR	0 dB SNR
Word Recognition	Single Task	Mean	98.2%	88.1%	70.4%	59.7%
		SD	0.01	0.04	0.11	0.09
	Dual Task	Mean	98.8%	89.8%	71.1%	60.3%
		SD	0.02	0.05	0.12	0.12
Serial Recall	Single Task	Mean	94.6%			
		SD	0.07			
	Dual Task	Mean	80.1%	72.4%	74.8%	68.2%
		SD	0.17	0.22	0.20	0.22

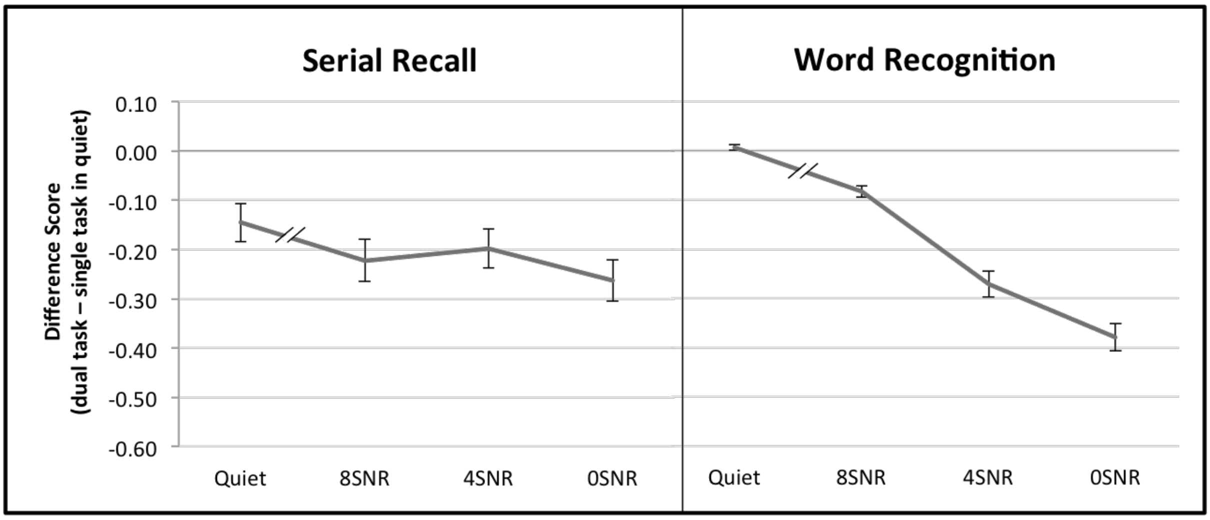

FIGURE 2: Normal Hearing Young Adults, 7-digit Recall

Discussion

Experiment II was designed to investigate the effect of capacity demands on dual task performance in adults with normal hearing by using a 7-digit recall task. For both word recognition and serial recall, performance was near ceiling in the single task in quiet (M=98% for word recognition, M=95% for serial recall); however, mean performance only dropped in the dual task condition for the serial recall task (M=80%). This reflects the nature of the dual task, such that performance declines on serial recall in order to maintain performance on word recognition. The addition of noise also impacted both tasks, however, serial recall performance was only affected when the SNR was 0 dB, the most difficult SNR used in this experiment. Thus, using the more difficult 7-digit task demonstrated an effect of noise on digit recall in the dual task that was not apparent in the 5-digit dual task, but only in the presence of high levels of noise.

As in Experiment I, the addition of noise resulted in decreased word recognition performance for adults with normal hearing. However, a comparison of the mean word recognition scores in the dual task conditions as a function of SNR shows very similar performance for the 5-digit dual tasks in Experiment I (Table 2) and the 7-digit dual tasks in Experiment II (Table 3). Thus, it does not appear that increasing the digit string size for a serial recall task had an impact on word recognition ability in the dual task paradigm. However, this observation may be a result of only examining young adult subjects with normal hearing. It is possible that increasing digit string size will have an impact on word recognition ability in a population known to have increased difficulty in noise. We explore this possibility in Experiment III.

EXPERIMENT III

The purpose of Experiment III was to examine the effects of perceptual demand and cognitive demand on word recognition and visual serial recall in older adults with sensorineural hearing loss. We used both a 5- and 7-digit serial recall tasks and predicted that older adults with hearing loss would show decreased word recognition ability when taxed with greater capacity demands (7-digit recall) compared with fewer demands (5-digit recall). We also hypothesized that the increased perceptual demands caused by increased background noise would decrease cognitive resources available for serial recall. This effect was expected to be greater for the older adults with hearing loss compared to younger adults with normal hearing.

Methods

Participants

Ten adults between the ages of 58-85 years (4 female, 6 male) were recruited from the University of Arizona Hearing Clinic and from flyers placed in the Speech and Hearing Sciences building on campus. Of these participants, 9 identified as Caucasian, and 1 identified as Hispanic. Participants were required to have a pure-tone average greater than or equal to 25 dB HL in both ears. The audiograms of all participants are summarized in Figure 3. Each participant passed a cognitive impairment screening by scoring at least 25 out of 30 (Crum, Anthony, Bassett, & Folstein; 1993) on the Mini-Mental State Exam (MMSE).

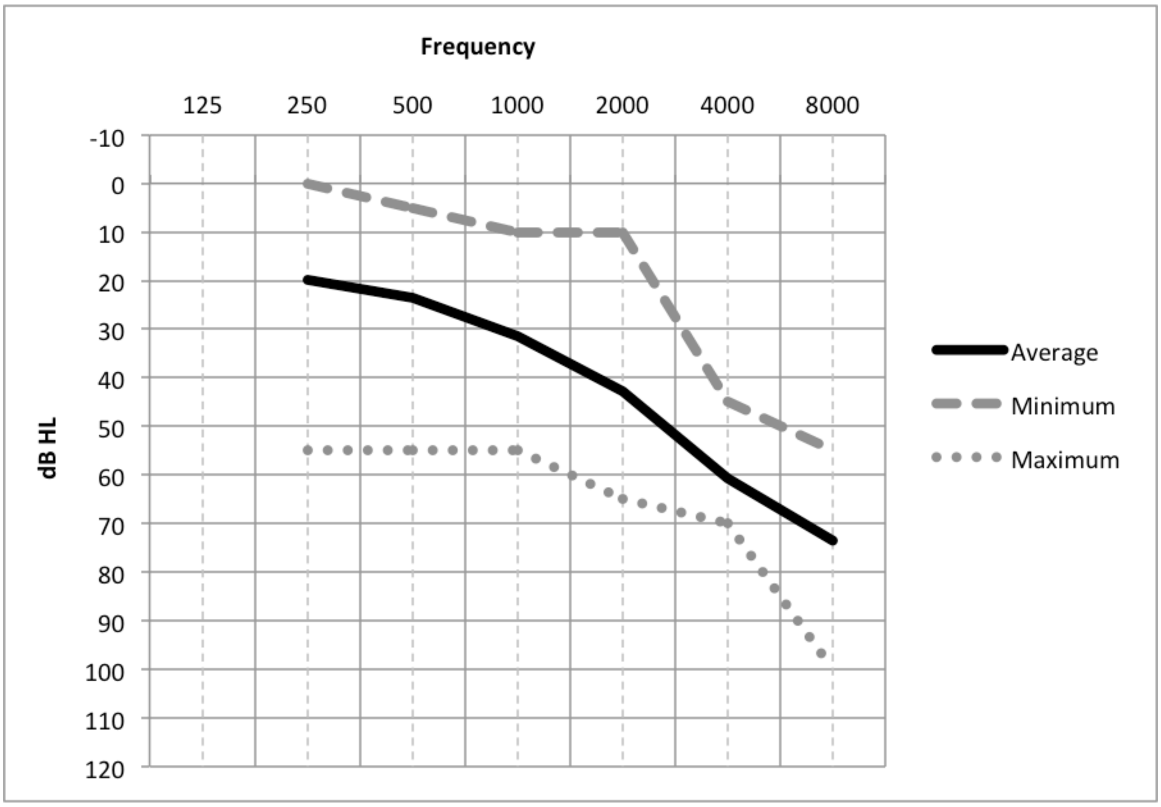

FIGURE 3: Audiometric Thresholds

Stimuli and Procedures

The stimuli and procedures are described in the general methods section. For the visual serial recall tasks, 5-digit and 7-digit serial strings were used, thus each participant performed the dual-task portion twice with the order of presentation counterbalanced. For the word recognition task, practice trials were presented at a +24 dB SNR. The SNRs for the experimental conditions were +16, +12, and +8 dB. These SNRs were chosen based on pilot data collection on older adults with hearing loss that showed non-asymptotic performance at these SNRs for this dual task. The number of trials for the dual and single task word recognition was increased to 5 trials, from 4 trials, for a total possible score of 75 phonemes. The presentation level of the speech was determined using a criterion level procedure for each participant.

Criterion Level Procedure. Since hearing ability was variable between participants, the level of presentation for each participant was determined through a criterion measure to ensure that the word stimuli were recognized optimally in quiet. The presentation level was chosen based on the point at which the participant could correctly repeat at least 90% of words presented in quiet. The most difficult NU-6 words lists were used (Hurley & Sells, 2003). The starting level presentation was always 40 dB above the participant's pure-tone-average. If a participant did not reach 90% correct identification at the starting level, the level of presentation was increased in 5 dB steps until he or she reached 90% correct. Every participant was required to reach 90% correct during the criterion procedure; however, during the experimental tasks, specifically single task word recognition in quiet, participants may or may not have reached 90% correct due to variability in word recognition performance.

Results

The means and standard deviations for the single and dual task word recognition and serial recall accuracy are presented in Table 3. In quiet, single task recall for 5 digits was near-ceiling (94.8%) with a slight decrease noted for the dual task (86.8%). Greater variability was noted for the dual task (SD=0.23) compared to the single task (SD=0.09), again reflecting greater individual differences in working memory abilities, which are taxed in a dual-task paradigm. Accuracy for single task 7-digit serial recall in quiet was 88.3% (SD = 0.13). Performance dropped to 57.8% in the dual task condition with high variability between subjects (SD=0.25). The difference scores used for the statistical analysis remove this source of variability since it is a within subject design and each subject is their own control.

TABLE 4: Means and Standard Deviations for Hearing-Impaired Adults

				Quiet	16 dB SNR	12 dB SNR	8 dB SNR
	Word Recognition	Single Task	Mean	92.9%	85.6%	74.8%	63.2%
			SD	0.08	0.10	0.18	0.19
5-digit	Word Recognition	Dual Task	Mean	95.2%	86.4%	77.7%	66.4%
			SD	0.07	0.07	0.17	0.24
	Serial Recall	Single Task	Mean	94.8%			
			SD	0.09			
		Dual Task	Mean	86.8%	84.4%	80.0%	79.2%
			SD	0.23	0.24	0.23	0.27
7-digit	Word Recognition	Dual Task	Mean	92.8%	84.7%	78.4%	61.1%
			SD	0.06	0.11	0.15	0.23
	Serial Recall	Single Task	Mean	88.3%			
			SD	0.13			
		Dual Task	Mean	57.8%	57.3%	58.9%	46.6%
			SD	0.25	0.23	0.20	0.25

Figure 4 displays the difference scores for the serial recall task and the word recognition task as a function of listening condition. An RMANOVA with listening condition (quiet, +16, +12, +8 dB) and digit string size (5 or 7) as the within subject factors was performed for both the serial recall difference scores and for the word recognition difference scores. For word recognition, there was a significant main effect of listening condition [$F(3, 27) = 14.7$, $p = 0.003$], and digit string size [$F(1, 9) = 6.9$, $p = 0.03$], but no interaction [$F(3, 27) = 0.87$, $p = 0.44$]. The overall mean difference score for the 7-digit string conditions ($M= -0.14$) was significantly larger than the overall mean for the 5-digit string ($M= -0.11$). Although the mean difference was small, overall, word recognition was generally more difficult for adults with hearing loss when they were asked to simultaneously perform a 7-digit compared to 5-digit serial recall task. The main effect of listening condition was evaluated using paired comparisons. The results showed that the difference scores for each SNR condition (i.e., -0.07, -0.15, -0.29 for the SNR +16dB, SNR +12dB, and SNR +8dB, respectively) were significantly larger (p < .01) than the difference score in quiet (M=0.01).

For serial recall, there was a significant main effect of digit string size [F(1, 9) = 9.679, p = 0.01]. The average difference score was larger for the 7-digit string (M=-0.33) than for the 5-digit string (M=-0.12). This finding indicates that when compared to the single task, serial recall in the dual task was more difficult for the 7-digit compared to the 5-digit strings. This was true regardless of listening condition. There was no significant effect of listening condition [F(3, 27) = 2.13, p = 0.12], and no interaction between digit string size and listening condition [F(3, 27) = 1.14, p = 0.35].

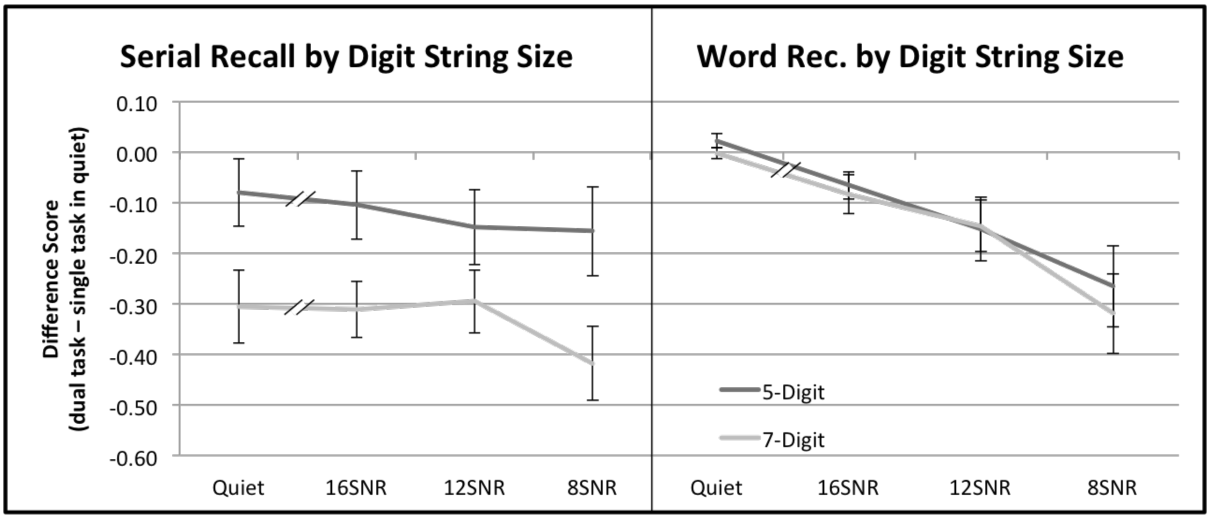

FIGURE 4: Hearing Impaired Older Adults

Discussion

It is clear that digit string size affected the participants' ability to recall the number string in the dual task condition. As the digit string size increased from 5-digits to 7-digits, the task became more difficult, and performance on serial recall declined. In this experiment, the addition of noise did not significantly impact serial recall. However, Figure 4 shows a trend suggesting that noise can make serial recall more difficult for some listeners, especially in high levels of noise (+8 dB SNR). In contrast to serial recall, there was a significant effect of listening condition on the word recognition task. That is, the addition of noise to the dual task significantly decreased word recognition performance compared to the single task in quiet. However, there was no meaningful effect of digit string size (5 versus 7) on word recognition ability, suggesting that word recognition performance was maintained even with increasing capacity demands.

Word recognition was more challenging in noise compared to in quiet for all listeners, which is consistent with the literature (Dubno, Dirks, & Morgan, 1984; Abel, Krever, & Alberti, 1990; Helfer & Wilbur, 1990). However, it appears that the older adults with hearing loss (Table 4) were impacted by capacity and perceptual demands to a greater degree than the younger adults with normal hearing (Table 3). To explore the differences in performance between younger adults with normal hearing and older adults with hearing loss we analyzed difference scores for the hearing impaired (Experiment III) with difference scores for the normal hearing (Experiment II) for the 7-digit recall conditions. The comparisons were made for the quiet and +8SNR listening conditions, because these were the only listening conditions that both normal-hearing and hearing-impaired adults performed.

Figure 5 displays the difference scores for normal-hearing (n=19) compared to hearing-impaired (n=10) adults for 7-digit recall as a function of listening condition. An RMANOVA with the within group factor of listening condition (quiet and +8 SNR) and the between group factor of group (normal-hearing vs. hearing-impaired) was performed for word recognition and for serial recall. For word recognition, the RMANOVA revealed a significant main effect of listening condition [$F(1, 27) = 46.384$, $p < 0.01$], a significant main effect of group [$F(1, 27) = 16.204$, $p < 0.01$] and a significant interaction between group and listening condition [$F(1, 27) = 14.373$, $p <$

0.01]. The significant interaction between group and listening condition was evaluated using pairwise comparisons with a Bonferroni correction and showed that both the normal-hearing and hearing-impaired groups had significantly larger difference scores ($p<0.001$) in the +8 SNR (-.08 and -0.32 for normal and hearing-impaired, respectively) compared to the Quiet condition (0.007 and -0.002 for normal and hearing-impaired, respectively). Although in the Quiet condition the mean difference score for the normal-hearing group ($M=0.007$) and hearing-impaired group ($M=-0.002$) were not significantly different from each other ($p=.54$), in the +8 SNR the mean difference score for the hearing-impaired group ($M=-0.32$) was significantly larger than the mean for the normal hearing group ($M=-0.08$), $p<0.001$. Thus, the older adults with hearing loss showed a greater decrement in dual task performance than the normal hearing adults, when noise was added. This is not surprising, as speech perception in noise is known to be more difficult for individuals with hearing loss compared to individuals with normal hearing (Dubno, Dirks, & Morgan, 1984; Abel, Krever, & Alberti, 1990; Helfer & Wilbur, 1990).

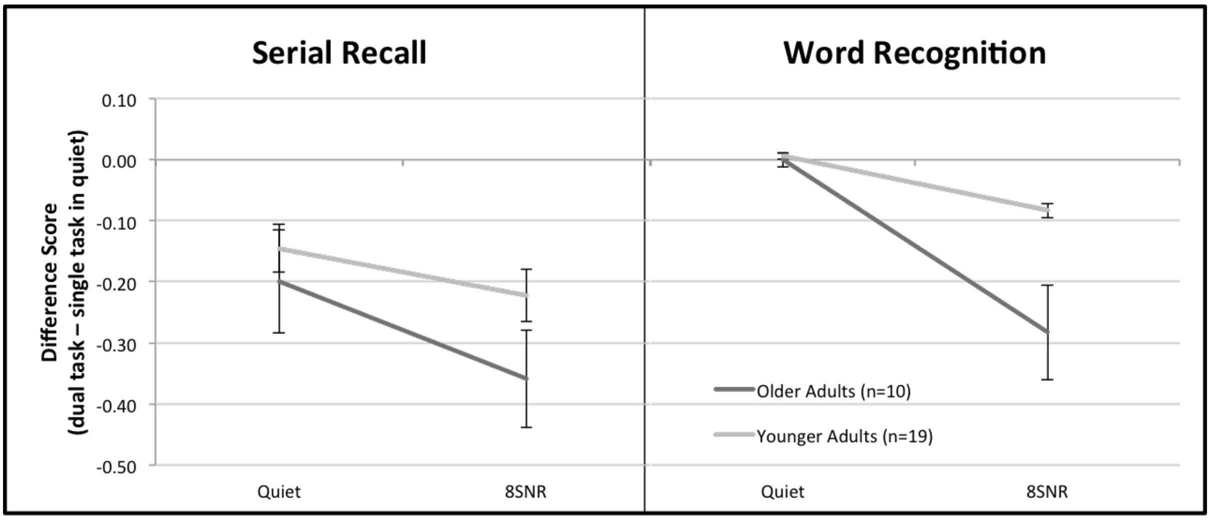

FIGURE 5: Normal Hearing vs. Hearing Impaired

For serial recall, the RMANOVA revealed a significant main effect of listening condition [$F(1, 27) = 5.265$, $p = 0.03$], with no interaction between listening condition and group [$F(1, 27) = 0.17$, $p = 0.68$]. The addition of noise to the dual task resulted in decreased performance in serial recall for both groups, beyond the performance cost of the dual task (Quiet condition). In other words, it was more difficult for both groups to recall a 7-digit string while also recognizing words in noise, compared to performing the same task in quiet. Also significant was the main effect of group [$F(1, 27) = 7.672$, $p = 0.01$]. Serial recall in the dual task was more difficult for the hearing-impaired compared to the normal hearing adults.

In summary, this analysis shows that individuals with hearing loss had more difficulty recalling a 7-digit string in the dual task, for both quiet and noise conditions, than the individuals with normal hearing. The addition of noise to the word recognition task had an impact on serial recall for both groups of adults when the tasks were performed in a dual task paradigm. For word recognition performance, the noise had a greater impact for those with hearing loss compared to those with normal hearing. In addition, adults with hearing loss had more trouble multitasking (greater decline on a secondary task) than normally hearing individuals. However, due to the lack of a subject group of young adults with hearing loss, it is unclear if this finding is the result of hearing loss or merely a difference in working memory capacity.

GENERAL DISCUSSION

Experimental Findings

The overall aim of this study was to investigate perceptual and capacity demands during a dual task involving word recognition and visual serial recall. The first and second experiments examined the effects of instructional emphasis, background noise, and digit string size in young adults with normal hearing. The findings indicated that instructional emphasis had no influence on digit recall or word recognition performance in the dual task conditions. This suggests that adults were not able to use top-down attentional processes to control their performance, similar to the children studied by Choi et al. (2008). When background noise was added, word recognition scores declined for all the young adult subjects, as expected. Surprisingly, 5-digit serial recall did not show a performance decline with increasing noise. It is likely that 5-digit recall was too easy for our young adult subjects; therefore, in Experiment II, capacity demands were increased by using 7-digit serial recall. For these subjects, serial recall performance during the dual task did decline with noise, but only in the most difficult listening condition (0 dB SNR). Interestingly, word recognition performance for the 5-digit and the 7-digit dual tasks were similar, implying that increased digit string size did not have an impact on word recognition ability for young adults.

Experiment III aimed to further explore perceptual and capacity demands in older adults with sensorineural hearing loss, using the same dual task as Experiment I and II. As with the adults with normal hearing, dual task performance on word recognition declined with increased background noise. The hearing-impaired adults also had greater difficulty recognizing words while simultaneously performing the 7-digit recall task compared to the 5-digit recall task. Although this difference was small (M= -0.14, for 5-digit string; M= -0.11, for 7-digit string) it is worth exploring in future studies the possibility that word recognition declines in individuals with hearing loss when capacity demands are high. In contrast, there was a clear decline on serial recall performance, in the dual task, when digit string size increased from 5-digits to 7-digits. Unexpectedly, the addition of noise did not have a statistically significant impact on serial recall; however, there was a trend suggesting that noise can make digit recall more difficult for some listeners, especially in high levels of noise (high variability between listeners).

Hearing Impaired Compared to Normal Hearing

From the raw data, it appeared that the older adults with hearing loss were impacted by perceptual and capacity demands to a greater degree than the younger adults with normal hearing. An analysis of difference scores for the hearing-impaired (Experiment III) compared to the normal hearing adults (Experiment II) for the 7-digit recall conditions, in quiet and +8 dB SNR, revealed that background noise impacted word recognition and serial recall performance for both groups. As expected, noise had a greater impact on word recognition performance for those with hearing loss compared to those with normal hearing. Interestingly, the individuals with hearing loss had more difficulty recalling a 7-digit string in the dual task, suggesting more difficulty dividing resources among tasks or simply less capacity, than normal hearing individuals.

The lack of a difference between single and dual task for word recognition in quiet, compared to the decrease in performance during the dual task for serial recall in quiet provides support for the effortfulness hypothesis; it suggests that processing resources were used to maintain performance on word recognition, leaving fewer resources available to perform a secondary task, especially in difficult listening environments. This was true for both the young adults with normal hearing and the older adults with hearing loss.

Clinical Implications

Clinically, standard speech testing involves word recognition in quiet, but it is becoming more common to assess sentence recognition in noise as well (Taylor, 2003). Research has suggested that performance on speech tasks presented in noise may be predictive of hearing aid benefit (Walden & Walden 2004), and are thus an essential part of a clinical test battery. The results of this study also support the need for speech in noise testing in the clinic. Both younger adults with normal hearing and older adults with hearing loss showed a marked decline in word recognition with increasing noise. Both groups also showed decreased serial recall ability in noise in a dual task compared to single task in quiet. This finding is consistent with Marrone et al. (2015) who suggested that even low levels of noise might affect the ability of young adults with normal hearing to perform memory tasks. As such, it can be expected that when demands are increased the effect of noise will also increase.

In the real world, individuals with hearing loss will likely be required to multitask in difficult listening environments. Thus, it is important to have an understanding of their ability to perform multiple tasks in noise. Performance on secondary tasks provides information about the amount of resources available to an individual and the effort involved in completing the primary task. Knowledge of an individual's resource capacity and listening effort while performing speech perception tasks are essential for providing appropriate treatment recommendations. In the future, it would be important to examine clinical measures that could be implemented to quantify resource capacity and listening effort.

Limitations and Future Directions

A few aspects of the methods limit the results of this study. First, the experimental design differed slightly between the normal hearing and hearing-impaired adults. The normal hearing adult subjects performed either the 5-digit tasks or the 7-digit tasks (between subject comparison), while the hearing impaired adult subjects performed both (within subject comparison). As a result, some statistical analyses directly comparing the normal hearing adults to the hearing-impaired adults could not be performed.

Second, the dual task presented in the present study is not particularly reflective of everyday life for two reasons: the speech and background noise were presented from the same spatial location and the multitasking portion involved memorization. Spatially separating the speech from the noise would create a more realistic listening environment, in which there are multiple distracting sound sources surrounding the listener. It is possible that spatial separation between sources could be used as a cue to sound segregation, which may result in a release from masking and reduction in the cognitive demands of the listening task (e.g., Marrone, Mason, and Kidd, 2008). However, other data indicates that spatial separation increases the costs associated with performing dual tasks (Helfer, Chevalier, & Freyman, 2010). Utilization of a dual task design involving a motor task, instead of a memorization task, along with speech recognition would reflect more common multitasking situations, such as, driving or walking while talking. There is some evidence to suggest that older adults experience more difficulty multitasking while driving (Wood et al., 2006).

Third, our study did not include a group of older adults with normal hearing. As such, it is impossible to separate out the effect of age versus the effect of hearing loss on the results in Experiment III. A recent study by Degeest, Keppler & Corthals (2015) utilized a similar dual-task paradigm to the present study with monosyllabic word recognition in noise and a visual memory task (sequences of geometric positions). Degeest et al. (2015) found that age significantly predicted listening effort in varying degrees of background noise, whereby listening effort increased with increasing age. Listening effort [calculated as 100 x (baseline – dual-task)/baseline] began to increase around 41 years for the +2 dB SNR condition and around 44 years for the -10 dB SNR condition. Since all the subjects had normal age-adjusted hearing thresholds, the authors speculated that cognitive abilities, such as working memory, processing speed, and selective attention, affected the increase in listening effort apart from hearing acuity. There is little consensus within the literature about the appropriate terminology concerning the cognitive factors involved in the present kind of dual task. Working memory demand, cognitive load, and listening effort are difficult to tease apart and likely refer to overlapping concepts (c.f., McGarrigle et al., 2014). More research in this area is required before concrete statements can be made about the exact mechanisms behind the observed dual task effects on performance.

In the future, we plan to expand on the results of the present study by testing not only older adults with normal hearing but also younger adults with hearing loss. There is a need for research concerning the effects of hearing loss alone on tasks involving high perceptual and capacity demands. Additionally, it would be interesting to investigate the effects of different hearing aid programs on dual task performance. There is some evidence to suggest that certain signal processing algorithms within hearing aid programs may decrease listening effort (Sarampalis, Kalluri, Edwards, & Hafter, 2009). In order to more readily apply this research to real life, it will also be important to investigate the relation between subjective and objective measures of listening effort. As such, questionnaires concerning task difficulty, such as the speech, spatial, and qualities (SSQ) hearing scale, should be included in the experimental design (Gatehouse & Noble, 2004).

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