THE EFFECTS OF BACKGROUND NOISE ON MULTITASKING

By

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A Thesis Submitted to The Honors College
In Partial Fulfillment of the Bachelors degree
With Honors in
Speech, Language, and Hearing Sciences
THE UNIVERSITY OF ARIZONA
MAY 2013

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The Effects of Background Noise on Multitasking

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Degree title (eg BA, BS, BSE, BSB, BFA):
BS

Honors area (eg Molecular and Cellular Biology, English, Studio Art):
Speech, Language, and Hearing Sciences

Date thesis submitted to Honors College:
May 1st 2013

Title of Honors thesis:
The Effects of Background Noise on Multitasking

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Abstract

Multitasking in background noise may involve greater cognitive processing demands than multitasking in quiet due to an increase in listening effort (Rabbitt, 1968; Pichora-Fuller and Schneider, 2000). This study investigated the effect of background noise in the listening environment on the ability to perceive speech while performing a secondary task. A dual-task paradigm was chosen based on theories of attentional limitations (Broadbent, 1958; Kahneman, 1973; Pashler & Johnston, 1998). Forty-five native English speakers between 19-25 years of age with pure-tone thresholds within normal limits participated in the experiment. Word recognition and visual serial recall were selected as the dual-tasks because both require processing capacity in the phonological loop of working memory (Baddeley, 2003). The number of digits to be recalled was varied in order to increase cognitive demands and test the hypothesis that background noise would degrade multitasking abilities more in more difficult tasks. Results show a gradual decline in the ability to recall the digits with a decline in SNR value of the words in noise. This effect is increased when the number of digits to be recalled increases. Therefore, these results suggest that background noise can have negative effects on the ability to multitask, especially when task demands are increased.

Keywords: effortfulness hypothesis, background noise, dual-task, word recognition, visual serial recall
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Introduction

Multitasking in noisy environments is a common experience in everyday life and the ability to understand speech in these situations is essential for communication and social interaction. Often, when people complain of decreased auditory comprehension in noisy environments, they are experiencing a limited ability to discriminate the target speech sounds from the background noise. In this case, raising the volume of the target speech will not necessarily aid comprehension. This effect of decreased audibility is greatly compounded in older adults, and especially older adults with hearing loss, who exhibit naturally occurring age-related declines. Age-related cognitive declines have often been proposed as a major factor in the capacity to comprehend speech in noise. This age-related decrease in speech understanding has been found for compressed speech (Wingfield 2006), decreased presentation levels (Baldwin 2011), dual-tasks (Gosselin & Gagne 2011), and low context situations (Wingfield 2006).

McCoy et al. (2005) has suggested an effortfulness hypothesis to explain the effect of limited cognitive resources on auditory comprehension. The effortfulness hypothesis states that in difficult listening situations, more cognitive resources are spent on hearing speech, which in turn leaves fewer resources available for processing that information or for performing a simultaneous task. It is possible that multitasking in background noise may involve greater cognitive processing demands than in quiet due to an increase in listening effort, which would in turn result in decreased comprehension (Rabbitt, 1968).

Individuals with hearing loss experience the effects of the effortfulness hypothesis to an even larger degree, due to an increased effort required when identifying a degraded signal, resulting in even poorer performance in noisy environments (Wingfield et al. 2005). In an attempt to increase audibility, individuals with hearing loss are supplied hearing aids with the ultimate goal of enabling them to communicate effectively. However, in noisy environments, a hearing aid also increases the noise, thus, the signal-to-noise ratio (SNR) remains the same. This suggests that the hearing aid user would not benefit in noisy situations with a hearing aid that amplifies all sound instead of only the target sounds. As a result, noise reduction (NR) algorithms have been designed to try to decrease the amount of noise that is amplified by hearing aids and ultimately create a favorable SNR. Sarampalis et al. (2009) tested the NR hearing aid
algorithm in order to determine the scope of its benefit, specifically whether benefit would go beyond accuracy in speech perception and impact listening effort. It was found that the NR algorithm benefit was only measurable on the secondary cognitive tasks. For example, when the participants were asked to repeat the final word of sentences in noise they did not benefit with NR, but when they were then asked to recall the last 8 words they had repeated the participants performed better with NR. This finding suggests that even though the participants were able to identify the words without NR, when NR was used it made identification easier and thus freed-up processing resources for other tasks. Further testing is required in this field so as to solidify a better understanding of the benefit of hearing aid algorithms on the interaction between auditory and cognitive processing.

In order to understand the difficulty that older adults with and without hearing loss experience in noisy environments, it is an important starting point to also consider the effects of noise on young adults with normal hearing. Rabbitt (1968) conducted several experiments that explored the effects of noise on speech perception in participants with normal hearing. The results provided evidence for the idea that individuals with normal hearing also experience decrements in performance when participating in tasks that involve background noise. For example, the first half of an 8-digit number was better recalled when the second half was presented in quiet rather than in noise, and comprehension of narrative passages was better if presented in quiet rather than noise. The data presented by Rabbitt (1968) suggests that normal hearing individuals also experience the effects of limited auditory processing capacity, resulting in less available resources for processing speech in noisy environments. The effortfulness hypothesis predicts that older adults and people with hearing loss experience this phenomenon to a much larger degree (Wingfield 2009).

There are many ways to assess the availability of auditory processing resources and effortful listening, but one of the most common is a dual-task paradigm. The dual-task design involves performing two tasks simultaneously; this creates an effortful environment in which more processing resources are used to attend to one task, leaving fewer available resources for the other task (Howard, Munro, & Plack, 2010). If auditory-cognitive resources are shared, the limited availability of resources will result in a decrement in task performance when comparing the results of each task performed separately to the results when they are performed together. This is referred to as the “cost” of the dual-task. Wingfield et al. (2009) conducted a dual-task
experiment on four groups (old/young, good hearing/poor hearing) in which the participants were asked to use a cursor to track a circle on a computer screen, then recall a list of words after a 30 second pause, and finally recall words while tracking the circle. In the results, the participant’s tracking cost was calculated by taking the difference between the single task and dual-task tracking accuracy. As expected, all the participants experienced a tracking cost due to the effortful environment created by the dual-task scenario. It was also found that the older adults displayed a larger cost than the younger adults and the participants with poor hearing showed an even larger cost than those with good hearing. Consequently, the participants who were older adults with poor hearing performed the worst on the dual-task and displayed the largest amount of tracking costs.

The purpose of this study was to design a dual-task paradigm to test the effortfulness hypothesis within young adults with hearing thresholds below 20dB HL. The paradigm included word recognition in noise and visual serial recall as a secondary task. Visual serial recall was chosen as a secondary task because mental rehearsal of digits to be recalled interferes with the working memory involved in recognizing and repeating words (Baddeley, 2003). The word recognition task included a quiet condition and three noise conditions with different signal-to-noise ratios: 0 SNR, +4 SNR, and +8 SNR. The visual serial recall task was comprised of either 5-digit numbers or 7-digit numbers. The amount of numbers was varied in order to test the hypothesis that noise will have an increased effect on performance as task demands increase.

This study investigated the effect of background noise on the ability to perform multiple tasks. In addition, the study tested the interaction of noise and task difficulty. Finally, the performance cost of multitasking was also used as a dependent variable. Based on the effortfulness hypothesis, the prediction is that there will be a decrement in secondary task performance, which will support the hypothesis that auditory processing has a finite capacity and is influenced by listening conditions. It is also expected that the cost of multitasking will increase with increased task difficulty, which will support the hypothesis that the effect of background noise multiplies with greater cognitive demands.
Method

Participants

Forty-five native English speakers with normal hearing were the first group to be tested. One participant was excluded from data analysis due to a prior diagnosis of attention disability and two other participants were excluded because they were non-native English speakers. As a result, 42 participants were included in the data. Each of the 42 subjects was between the ages of 19-25 years old and all of them had pure-tone thresholds below 20 dB HL for all frequencies tested. Most of the participants were students receiving extra credit for their participation in the research study; others were given monetary compensation for their time.

Hearing Thresholds

In order to ensure eligibility for participation, pure-tone and speech audiometry were assessed. Participants were required to have pure-tone thresholds (250-8000 Hz) better than or equal to 20 dB HL across frequencies and a speech reception threshold in agreement with the pure-tone average. This was done using a computer-based audiometer and insert earphones (Aurical). Supra-aural headphones were used if the subject’s ears contained excessive cerumen that contra-indicated use of insert earphones.

Visual Serial Recall Single Task

All of the tasks were created using PowerPoint and presented to the subject through a portable touch screen device. This task included a total of 10 trials, 5 of which were presented in quiet and the other 5 in noise. The participant was prompted with an audio recording of “Look at the numbers” and then presented a number on the portable screen for 3 seconds. Next, they were instructed to think about that number for 20 seconds. Finally, they were prompted with an audio recording of “Say the number” requiring them to repeat the number. The participants were divided into two groups: Group 1 consisted of 23 subjects who were presented 5-digit numbers, and Group 2 consisted of 19 subjects who were presented 7-digit numbers.

Word Single Task Recognition

This task included of a total of 16 trials consisting of 4 trials in quiet, 4 trials in noise with a +8 SNR, 4 trials in noise with a +4 SNR, and 4 trials in noise with +0 SNR. Each trial
consisted of 5 monosyllabic words taken from the Words In Noise (WIN) lists (Wilson & McArdle, 2007). The words and the noise were presented to the subject through a single loudspeaker inside the sound booth. The subjects were instructed to listen to each word and repeat them aloud. If they were unsure what the word was, they were told to take a guess. For 12 of the subjects, the words were presented at 40 dB HL above their SRT and for the other 30 subjects they were presented at 20 dB HL above their SRT.

**Dual-Task**

For the final task, the subjects were asked to complete a combination of the visual serial recall task and the word recognition task. First, the participant was prompted with “Look at the number” and presented a number on the screen. Then they were presented 5 WIN words for 20 seconds. They were instructed to remember the number while they repeated the words aloud. At the end of the trial they were prompted with “Say the numbers,” requiring them to recall the number. This task included a total of 18 trials consisting of 2 practice trials with a +16 SNR, 4 trials in quiet, 4 in noise with a +8 SNR, 4 in noise with a +4 SNR, and 4 in noise with +0 SNR. Again, the words were presented at 40 dB SL for 12 subjects and 20 dB SL for 30 subjects. Also, Group 1 was presented 5-digit numbers and Group 2 was presented 7-digit numbers.

**Dual-Task Example Trial**

<table>
<thead>
<tr>
<th>Audio</th>
<th>“Look at the numbers”</th>
<th>“judge red base wire time” (multi-talker babble)</th>
<th>“Say the numbers”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>6 7 1 6 5 9 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Controls**

To control for possibility that the participants would use different strategies while performing the dual-task, they were given a listening strategy. One group was instructed to focus on correctly recalling the digits while a second group was instructed to focus on word recognition. To control for future testing on older adults with hearing loss who exhibit a small
dynamic range, one group of participants was presented the stimuli to two groups of participants at different sensation levels above the SRT (20 dB SL and 40 dB SL).

**Procedure**

After the subject signed a consent form and completed a short questionnaire, their ears were checked for cerumen by otoscopy. Next, the subject’s pure-tone thresholds and SRT were obtained. Finally, they were required to complete the digit single task, the words single task, and then the dual-task. All participants completed the tasks in this exact order. At the end of the session, the subject’s were either given $10 per hour or received extra credit for their participation. Typically, each session lasted about an hour.

**Results**

Repeated measures analysis of variance (RMANOVA) were performed on the data using SPSS software. For word recognition, it was determined that neither emphasis nor presentation level had statistically significant effects (single vs. dual-task x 4 SNR x 3 between-group measures RMANOVA, $p > 0.05$). Similarly, for visual serial recall, it was determined that neither emphasis nor presentation level were statistically significant (2 task by 2 SNR by 3 between group measures RMANOVA, $p > 0.05$). As such, these measures were not included in the representations of the data. **Table 1** describes the data, in terms of means and standard deviations, for all of the factors that showed significant main effects or interactions. Additional statistical analyses are described below.
Table 1: Statistical Summary

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of digits</th>
<th>SNR</th>
<th>Word Recognition</th>
<th>Visual Serial Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
<td>Mean</td>
</tr>
<tr>
<td>Single</td>
<td>5</td>
<td>Quiet</td>
<td>0.98</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+8</td>
<td>0.87</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+4</td>
<td>0.72</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0.58</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Quiet</td>
<td>0.98</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+8</td>
<td>0.88</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+4</td>
<td>0.70</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0.59</td>
<td>0.11</td>
</tr>
<tr>
<td>Dual</td>
<td>5</td>
<td>Quiet</td>
<td>0.99</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+8</td>
<td>0.87</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+4</td>
<td>0.76</td>
<td>0.13</td>
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<tr>
<td></td>
<td></td>
<td>0</td>
<td>0.59</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Quiet</td>
<td>0.97</td>
<td>0.02</td>
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<tr>
<td></td>
<td></td>
<td>+8</td>
<td>0.90</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+4</td>
<td>0.71</td>
<td>0.12</td>
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<tr>
<td></td>
<td></td>
<td>0</td>
<td>0.60</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 1. The means and standard deviations of all experimental factors.

Recognition and Recall Accuracy

For word recognition, there was a significant main effect of SNR ($p < .001$). That is, performance decreased as the background noise increased. Figure 1 displays the word recognition accuracy scores of all 42 participants. Scores were calculated based on percent of phonemes correctly produced out of the total possible number of phonemes. The figure shows a decreased ability to recognize the words as the amount of background noise increased. It also shows that there was not a significant difference between performance on the word recognition between the single and dual-tasks. Therefore, there was no cost associated with completing dual-tasks on word recognition accuracy.
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Figure 1: Word Recognition Accuracy

**Figure 1.** Word recognition accuracy as a function of signal-to-noise ratio. The dark red bars indicate percent scores for single task word recognition and the light pink bars indicate percent scores for dual-task word recognition.

**Significant effect of signal-to-noise ratio (p < .001)**

For visual serial recall, there were significant main effects of task (p < .001) and SNR (p < .02). This means that performance decreased when recalling the numbers in background noise as well as decreased during the dual-task. **Figure 2** displays the visual serial recall accuracy scores of all 42 participants. Scores were calculated based on percent of digits correctly recalled, in correct order, out of the total number of possible digits. The figure shows a decreased ability to recall the numbers when background noise was present. It also shows that the cost of the dual-task only served to add to the detrimental effect of background noise. There was also a borderline interaction for task by number of digits by emphasis (p = .08).
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**Figure 2.** Visual serial recall accuracy as a function of listening condition. The dark blue bars indicate percent scores for single task visual serial recall and the light blue bars indicate percent scores for dual-task visual serial recall.

**Significant effect of task ($p < .001$)**

* Significant effect of SNR ($p < .02$)

**Recognition and Recall Cost Scores**

The cost scores were calculated using a subtraction relative to each individual’s single task score (formula: (single task percent score – dual-task percent score)/single task percent score). For word recognition, there was not a significant effect of task or number of digits $p > 0.05$. Performance on word recognition under single and dual-tasks was essentially the same at each noise condition tested, regardless of the number of digits to be remembered (see Table 1). **Figure 3** shows a slight increase in the ability to recognize the words during the dual-task; however, it was not statistically significant ($p > .05$). For visual serial recall there was a significant effect of SNR by number of digits ($p < .001$). In addition, performance also decreased significantly when there was background noise for 7-digits, resulting in the greatest cost during the 7-digit noise condition. **Figure 4** displays an increased dual-task cost for recalling a 7-digit number as opposed to a 5-digit number. It also shows an even greater cost when the 7-digit number was presented in noise compared to the quiet condition.
**Figure 3.** Word recognition cost scores as a function of signal-to-noise ratio. The dark red bars indicate cost scores for word recognition with 5-digit visual serial recall as the secondary task. The light pink bars indicate cost scores for word recognition with 7-digit visual serial recall as the secondary task.

**Figure 4.** Visual serial recall cost scores as a function of listening condition. The dark blue bars indicate cost scores for 5-digit visual serial recall and the light blue bars indicate cost scores for 7-digit visual serial recall.

**Significant effect of number of digits by SNR (p < .001)**
Discussion

This study was designed to answer three research questions: 1) Does background noise affect the ability to perform multiple tasks? 2) How does task difficulty interact with the effect of noise? and 3) Is there a performance cost to multitasking? Based on the statistical analysis of the data, it was found that there was a significant effect of noise on both word recognition and digit recall tasks, there was a significant effect of the number of digits to be recalled, and finally there was a significant effect of performing dual-tasks that was measurable on visual recall. Therefore, the results of this dual-task paradigm suggest that: 1) Performance on both tasks decreased with increased background noise, 2) Performance decreased as the number of digits increased, and 3) Performance on the visual serial recall reflected a dual-task cost that increased with added task difficulty.

These experimental results support the effortfulness hypothesis because as the noise increased, the cost of the dual-task also increased. This means that the subjects displayed limited processing resources as they performed two simultaneous tasks. Additionally, background noise only serves to exacerbate these negative effects. The results also show that multitasking has detrimental effects not only on older adults (as in previous studies) but also on young adults (data collected here). The fact that there was a dual-task cost seen for only the visual serial recall measure may suggest that subjects allocated more cognitive resources to word recognition, leaving fewer resources for recalling the digits. In other words, the subjects may have used more resources attempting to discriminate and repeat the speech in background noise, which in turn resulted in fewer resources left to devote to remembering the digits. This can help to explain why it is so difficult to understand speech in noisy environments; the difficult task of discriminating speech in background noise seems to require a large amount of processing resources, which results in fewer resources left for cognitive processing of that information. This is consistent with observations that it is possible to hear speech and not be able to comprehend the meaning of what was said in noisy environments.

Additional findings showed a slight increase in word recognition performance during the dual-task as opposed to the single task (see Figure 3). It is possible that as the difficulty of the task increases, there is increased effort placed on maintaining performance in noise. However, further research in this area is needed to confirm this hypothesis.
The results of this study also support Howard, Munro & Plack’s (2010) research concerning children’s ability to perform dual-tasks. Consistent with the present study, Howard, Munro & Plack’s (2010) study utilized word recognition in noise as a primary task and visual serial recall as a secondary task. They found that children, between 9 and 12 years old, experienced a performance decrease in word recognition as the noise increased as well as a cost in visual serial recall when comparing single and dual-task scores. The current study is consistent with these results and supports the idea that background noise influences dual-task cost in both young adults and children. Next, it would be important to consider the effect that background noise has on the ability for older adults and individuals with hearing aids to perform multiple tasks. It is well known that older adults and hearing aid users experience more difficulty in noisy situations than their younger counterparts. The most common complaint of older adults with hearing loss is that they can hear speech but they can’t understand it. Furthermore, there is evidence to support that older adults specifically have difficulty multitasking (Gatehouse & Noble, 2004). However, to date, there is not an efficient way to measure the magnitude of difficulty or the benefit of hearing aid algorithms on these types of tasks.

Traditionally, hearing aid signal processing algorithms have been considered to have limited benefit in cases where word recognition test results display no change in performance. However, a recent study has suggested that at least noise reduction algorithms display a benefit on secondary cognitive tasks, even when there is no change in word recognition (Sarampalis et al., 2009). As a result, a dual-task paradigm that includes background noise could be used in the clinical realm to determine if a particular patient is receiving a benefit from hearing aid algorithms intended to create favorable SNRs. The dual-task paradigm designed for the present study has been shown to create the expected cost in cognitive resources. Therefore, in the future it may be possible to utilize this dual-task design and adapt it for more rapid testing time to determine the clinical outcomes with particular hearing aid algorithms.

**Constraints and Future Directions**

In this study, the stimuli were presented from one audio loudspeaker in the sound field. As a result, the speech and background noise were presented from the same spatial location, which is not representative of most real-life situations. A more realistic listening environment
would be to spatially separate the speech and noise sources. In the future, we plan to convert the dual-task into a more ecologically valid experimental design using software that will allow us the use of multiple loudspeakers in the sound field (E-Prime). Presenting the speech from one loudspeaker and the noise from another will more accurately reflect real-life noisy environments such as a cocktail or dinner party. The spatial separation of the speech and noise could also cause a benefit in performance, due to better segregation of the speech and noise in the auditory system (e.g., spatial release from masking, Marrone, Mason, and Kidd, 2008).

For future testing, we also plan to recruit additional participant groups, including: older adults with hearing loss, older adults without hearing loss, and young adults with hearing loss. The ultimate goal is to create a clinical measure that tests the effectiveness of hearing aid algorithms on listening effort, and therefore, it is necessary to have standardized scores for all of these populations.

Acknowledgments

We gratefully acknowledge research assistants Daniel Bos and Alex Block for their help with data collection, Dr. Linda Norrix for insightful discussions of experimental design, and Dr. Mark Borgstrom for statistical consultation.
References


