The Effect of Word Frequency and Dual Tasks on Memory for Presentation Frequency

by

Megan Paige Peterson

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Graduate Supervisory Committee:

Tamiko Azuma, Chair
Shelley Gray
Julie Liss

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ABSTRACT

Frequency effects favoring high print-frequency words have been observed in frequency judgment memory tasks. Healthy young adults performed frequency judgment tasks; one group performed a single task while another group did the same task while alternating their attention to a secondary task (mathematical equations). Performance was assessed by correct and error responses, reaction times, and accuracy. Accuracy and reaction times were analyzed in terms of memory load (task condition), number of repetitions, effect of high vs. low print-frequency, and correlations with working memory span. Multinomial tree analyses were also completed to investigate source vs. item memory and revealed a mirror effect in episodic memory experiments (source memory), but a frequency advantage in span tasks (item memory). Interestingly enough, we did not observe an advantage for high working memory span individuals in frequency judgments, even when participants split their attention during the dual task (similar to a complex span task). However, we concluded that both the amount of attentional resources allocated and prior experience with an item affect how it is stored in memory.

DEDICATION

I dedicate this thesis to my parents, Renee and Randy Peterson for their endless love, encouragement, and support. They have backed me both financially and emotionally and have always prioritized my education above their own needs.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

The prefrontal cortex is associated with executive functioning, including reasoning, decision-making, working memory, planning, attention, self-monitoring and inhibition. It encompasses sequencing and organizing actions towards an ultimate goal (Fuster, 2008).

The concept of executive control of attentional resources is integral to working memory, inhibition, and planning. Working Memory (WM) is assumed to be a cognitive system that processes, manipulates, and temporarily stores information (Baddeley, 2003). Working Memory is "a temporary storage system under attention control that underpins our capacity for complex thought" (Baddeley, 2007). WM is a key construct in understanding many aspects of cognition and theorists have differing opinions about the configuration and assessment of WM. Most agree that the system provides limited flexible temporary storage and simultaneous manipulation of information of non-automatic processing which is retrieved from portions of long-term memory (LTM) (Baddeley 2007; Oberauer 2005; Unsworth & Engle, 2007). Capacity limitations are, however, greatly debated.

The Baddeley multicomponent model of WM describes a central executive and two slave systems: a phonological loop and a visuospatial sketchpad. Baddeley (2003) states that the visuospatial sketchpad is primarily located in the right hemisphere of the brain. More specifically, he argues it resides in the right inferior parietal cortex, the right premotor cortex, and the right inferior frontal cortex (Baddeley, 2003). The areas activated are specific to the type of stimuli. This "sketchpad" consists of two components: visual and spatial processing. Visual information includes the characteristics of an object, and spatial information relates to the locations of stimuli. Spatial information activates the right-hemisphere premotor cortex and the storage of object information activates other areas of the prefrontal cortex (Smith & Jonides, 1999).

The phonological loop processes linguistic information, such as phonemes or words. In neuroimaging, verbal information sustained in WM activates Broca's area and left-hemisphere supplementary and premotor areas (Smith & Jonides, 1999). The central executive oversees and allocates resources to the two slave systems. Baddeley considered the central executive to be a purely attentional source that is incapable of storage (2007). He proposed that it was housed in the frontal lobe, specifically the prefrontal cortex, and the anterior cingulate activate during selective attention (Baddeley, 2007; Smith & Jonides, 1999). Rather than compartmentalizing WM to the prefrontal cortex, it is more likely that WM relies on the functional interactions between the PFC and other dedicated regions of the brain (D'Esposito, 2007). Newer versions of the Baddeley model include an episodic buffer, which is responsible for processing and transferring information between WM and LTM (Baddeley, 2000). This system implies that information is transferred to a buffer for storage and processing. However, even Baddeley's most recent model of WM, which assumes three buffers, cannot accommodate the infinite amount of information requiring processing by the brain (D'Esposito, 2007).

Cowan's embedded-processes model (1999) is less compartmentalized than the Baddeley framework and conceptualizes WM in hierarchical activation levels. These levels include LTM at the lowest level that encompasses all divisions of LTM. The next, smaller level is the portion of long term memory that becomes activated above baseline by various degrees. Finally, the most highly activated potions of LTM are consciously held in the focus of attention at the top of the order. These are the items WM is acting upon. Oberauer's (2002) theoretical WM framework, similar to Cowan's embedded-processes model, assumes a model with hierarchically arranged subsets of elements represented in memory. Because of spreading activation, portions of LTM are activated as a response to external stimuli. Significantly smaller subsets of elements are in the central component of WM, the region of direct access (RDA). When they are activated, elements held in the RDA are immediately accessible for ongoing processing. As new items become activated, previously activated items decay over time. Bindings link items together in the RDA in serial order. To hold items in the RDA, individuals are constantly updating the system through creating and deleting bindings. Capacity limitations define the number of items that can be maintained at an activated level and held within the RDA. Working memory capacities (WMC) vary among individuals. Therefore, the number of items someone can actively maintain differs from person to person.

Attention plays a significant role in WM processing. Interference control or inhibition is an important aspect of attention. Inhibition prevents individuals from acting impulsively and blocks other information from interfering with the current cognitive task. When inhibition is impaired, individuals can become distracted by irrelevant stimuli. For example, participating in an important phone call in a sports stadium or busy mall would be taxing on inhibitory systems because of the numerous distractions. The person would need to inhibit the surrounding noises and sights and to focus their attention on processing the auditory message. Executive attention is key to both planning and decision-making. Planning is a complex frontal executive function rooted in episodic memory but in preparation for a future goal. Fuster (2008) describes a new "plan" as a "set of objectives, a new order, a new timetable, and a new ultimate goal that plan is essentially based on old experience of prior actions" (p. 354). A plan can be as simple as establishing the steps needed to change the television channel. Decision-making is highly correlated with "plans," but includes a motor component, or action (i.e. initiating the action of picking up the television remote and selecting a new station).

In regards to anatomical correlates, the orbitofrontal cortex is highly connected with the areas of the brain that weigh in on decision-making (Fuster, 2008). The prefrontal cortex receives information from associated areas of the brain and relies on long-term memory to continuously evaluate the potential outcomes of a decision. Studies using fMRI found that when verbal or spatial information was presented, the prefrontal region was more highly activated for integrated information indicating the importance of the prefrontal cortex in WM tasks (Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998; Prabhakaran, Narayanan, Zhao & Gabrieli, 2000). Additional studies have found that in dual-processing tasks, attention is a resource under executive control and that memory deficits are related to impairments in attention and/or executive control (Mangels, Craik, Levine, Schwartz & Stuss, 2002). Thus, these deficits may only present when task demands are high.

Damage to the frontal lobe may affect any of these processes and could result in executive dysfunction, working memory deficits, and attention deficits. Animal and human studies reveal that damage to the prefrontal cortex results in attention deficits characterized by distractibility, hyper-reactivity, and impulsivity (Baddeley, 2003). Similar cognitive impairments can be observed in individuals with acquired disorders such as stroke, tumors, traumatic brain injuries (TBI), or degenerative diseases. An increased repetitive response and decline in recognition memory has been reported in patients with aphasia, Alzheimer's, Huntington's, and Parkinson's disease (Albert, 1989; Borgo, Giovannini, Moro, Semenza, Arcicasa, & Zaramella, 2003). Patients with TBI often exhibit executive dysfunction characterized by loss of inhibition, poor decision making abilities, poor planning, and attention deficits resulting in decreased memory (Mangels et al., 2002). Even healthy older adults experience age-related declines in executive function including declines in working and recognition memory (Shimamura & Jurica, 1994, Troster, Salmon, McCullough, & Butters, 1989). Studies have found that increased chronological age is linked with decreased performance on alerting, orienting, and executive attention related to WM (Mahoney, 2010; Thompson-Schill, Jonides, Marshuetz, Smith, D'Esposito, Kan, Knight, & Swick, 2002). Various deficits manifest several ways, depending on the task demands.

Verbal fluency tasks are often incorporated into diagnostic assessments as a test of executive function. Verbal fluency tasks may be semantic or letter based. An example of a semantic category task includes listing as many animals as possible in 60 seconds. An example of a letter-based category is listing words that start with the letter "M". Fluent responses require several cognitive processes, including strategic search, suppression of previous responses, and maintenance of category. Therefore, analyzing responses of a verbal fluency task may provide an interventionist with further information regarding the nature of a disorder. The Cognitive Linguistic Quick Test (CLQT) is a valuable tool in assessing individuals with acquired cognitive deficits, such as those with associated with dementia, stroke, head injury, or Parkinson's disease (Helm-Estabrooks, 2001; Parashos, Johnson, Erickson-Davis & Wielinski, 2009). Perseveration rates are calculated as part of the CLQT. Perseverations include recurrent, stuck-in-set, and continuous perseveration. Recurrent perseveration can be described as repetition of a previously stated response; Stuck-in-set involves including information from a previous category (e.g. producing “cow” during the verbal fluency task of “m” words). Sometimes individuals repeat the same word over and over (continuous perseveration) (Albert, 1989). Perseveration is much less prominent in healthy adults than in clinician populations (Albert 1989; Ramage, Bayles, Helm-Estabrooks, & Cruz, 1999). Perseveration is an indication of cognitive dysfunction. If an individual is unable to monitor past responses and perseverates, it may indicate decreased working-memory capacity (Azuma, 2004).

Other measures of working memory capacity include simple and complex span tasks. Simple span tasks require participants to immediately recall lists of information and are said to measure short-term memory storage (STM). Complex WM tasks, or complex span tasks, measure the processing portion of WM by presenting a simultaneous task. There are a variety of complex span tasks designed to test WMC. The operation span (OpSpan) task is one test of WMC. OpSpan combines solving mathematical equations while attempting to remember words. For the processing portion, two-step equations are presented and participants must indicate whether each equation is correct or not (e.g. (6 / 3) + 3 = 5?) indicating “Yes” or “No” on a labeled keyboard. A to-be-remembered word follows each mathematical equation. Math-word pairs continue until the message “RECALL THE WORDS” prompts participants to recall the words in the presented order.

Reading span integrates language-based information by presenting to-be-recalled items (usually words) in alternation with sentences to comprehend (Daneman & Carpenter, 1980; Oberauer, 2005). WM processing varies among individuals, likely because of executive function differences. In contrast, STM storage is assumed to be relatively consistent across individuals. Because of the nature of WM span tasks, WMC is also a strong predictor of fluid intelligence (Gf) and other cognitive abilities (Conway, Jarrold, & Kane, 2007). Conway et al. also suggest that complex WM tasks, such as the OpSpan, should strongly correlate with other WMC tasks, such as the reading span or counting span (2007).

Unsworth and Engle (2007) argue that simple span tasks (measuring STM) and complex span tasks (measuring WM) are assessing the same system but different components (storage vs. processing). Complex span tasks present participants with immediate recall tasks as well as a secondary processing task of unrelated information. This requires individuals to use set switching (alternating attention) to maintain both sets of information and to suppress unnecessary information. Kane and Engle (2000) elaborated on this idea of capacity limitations related to interference susceptibility. They added that individual differences of WMC are dependent on controlled attention when activated portions of LTM are interrupted by environmental factors and interference. Dual-tasks require attention to two tasks and individuals allocate attentional resources to each task differently. Kane and Engle found that individuals with high WM spans use controlled attentional processing to resist interference but low-span individuals do not. They suggest that, for low-span individuals, encoding and retrieval may be no more attention demanding in the presence than in the absence of interference because they do not employ controlled attentional strategies well (Kane & Engle, 2000). An investigation by Fernandes and Moscovitch (2000) found that attentional resources differ depending on task requirements for divided attention tasks. During encoding, general resources are required and during retrieval tasks, systems compete for representational systems.

Long-term memory (LTM), specifically episodic memory, also plays a role in WMC tasks. Episodic memory, a component of declarative memory, involves the recollection of specific past events or experiences. Source memory refers to the context in which someone encountered specific information and relies heavily on episodic memory. Frequency judgment requires the person to determine how many times someone experienced a specific piece of information and is related to recency judgment, or how recently someone experienced something. If recency judgment is impaired, individuals could repeat a story in the same conversation or repeat a response in a test without realizing it. Frequency judgments are related to recency judgments because many times, people encounter the same information multiple times. Neurological systems regulate the "what" and the "where" of learned information. The "what" part of memory is mediated by the temporal lobe. The "where" and "how frequent" aspects of a memory are thought to be mediated by the posterior parietal cortex and the prefrontal cortex, including the dorsolateral prefrontal cortex assumed to be associated with WM as well (Haut, Arias, Moran, Leach, & Parsons, 2001). These systems integrate to help individuals decide whether a given piece of information is relevant for the current context through recollection or familiarity. When information was learned and where it was learned is critical for positive recollection. Familiarity strength can guide the decision process.

In Oberauer's (2005) theoretical framework, during recollection, the probe is compared to the contents held in the RDA. A match provides information about the context in which the probe was experienced. This comparison process is used to guide recollection-based decisions. Impairments to necessary aspects of memory may result in overestimations of the importance of information or incorrectly deem it as irrelevant. Familiarity is a quick process that can lead to false hits in WM tasks, but even high familiarity will have to be rejected on the basis of recollection.

Neuroimaging studies by Haut et al. (2001) support the separation of frequency and recognition memory. The left ventrolateral prefrontal cortex is activated with both frequency and recognition memory tasks. However, the hippocampus is suppressed during frequency memory. Given the hippocampus's association with episodic memory integration, this supports that idea that recognition memory draws from previous experiences.

Previous experiences with information can also affect recollection, as people will read the same words in many different contexts. Word frequency reflects the relative frequency that people will encounter the word; norms are based on frequency in language, specifically printed material. High frequency words are the most popular words found in printed material and low frequency words are least common (Kucera & Francis, 1967). Baddeley and Scott (1971) found that recall during simple span tasks was higher for high frequency words relative to low frequency words. Engle, Nations, and Cantor (1990) found that although STM and WM are measured with different tasks (simple vs. complex) both show similar word frequency effects. These effects (improved recall for more frequent words) seem to be smaller in complex span than in simple span tasks. Additionally, there is considerable variation between complex span tasks. More complex tasks that include divided attention or temporal order require more attentional control than memory strictly for item recall, such as with some STM tasks (Troyer & Craik, 2000). Unsworth and Engle (2007) theorize that complex tasks activate primary memory (PM), which activates a maintenance component and that simple tasks activate secondary memory (SM), a search and retrieval process of information that cannot be maintained in PM. Because high frequency words can be stored more strongly than low frequency words, they are more likely to be retrieved easily.

Lexical frequency has a different effect in other types of memory tests. For example, in a standard study-recognition test procedure, high frequency words tend to show lower hit rates and higher false alarms, relative to low frequency words. This effect is known as a word frequency "***mirror effect" (***Glanzer & Adams, 1985). There are many theories regarding the underlying mechanism for the mirror effect. One major theory proposes the effect occurs because individuals have had experiences with these high frequency words in many different contexts and these previous memory episodes interfere with memory for the specific study context (Dennis & Humphreys, 2001). Low frequency words have fewer memory traces to interfere with memory trace of the study episode. Frequency judgments are interesting because there will be multiple memory episodes within the same study task. It is unknown whether item memory or frequency memory of low frequency words will be affected more by multiple presentations than high frequency words.

This experiment examines the relationship between WM, word frequency, and the ability to track item presentations. Participants studied words and were later asked how many times a given word appeared in the study task. Their WM span was also measured using the OpSpan. The purpose of this study was to address three main questions:

1. Is there a relationship between WM span and the ability to judge repetition frequency?
2. Does printed frequency of the word affect accuracy of frequency judgments?
3. How does splitting attention affect the ability to monitor frequency?

The relationship between WM span and the ability to judge repetition frequency should result in a positive correlation if WM mediates the ability to maintain frequency information. Working memory capacity is limited by the amount of information individuals can hold in their RDA. Thus individuals with larger WMC should be able to use recollection to guide their frequency judgments by accessing these items. Low span individuals would have to rely more on familiarity and less on recollection. During recognition memory tasks, high frequency words are more likely to feel familiar to people. When a person is given a recognition test and they see a previously seen item, they know it is an old item because it is activated quickly and strongly (due to its recent activation in the study task). When people see a high frequency word, they are more likely to feel familiar to people because, similar to studied items, they will activate quickly and strongly. People may mistakenly think that they have seen those high frequency words more often in the study task. This would reflect a source memory error, mistaking an internal source (previous experiences) for an external source (the experience of seeing it on a computer screen). It was hypothesized that participants may overestimate the presentations of high frequency words relative to low frequency words. There may be a larger effect for participants with lower WM spans because of their reliance on familiarity over recollection memory because of lower WMC.

Directing attention during the study task is important for remembering item details (where and when). Splitting attention between two tasks requires the individual to allocate resources to two separate processes resulting in a competition for resources. Increasing the demands on attentional systems could result in decreased attention to one task and decreased memory strength for items in that task. In this study, one group of participants performed math problems during the study part of the experiment while the other group studied the words with no concurrent task. We were interested in studying if participants have to split their attention between two tasks when they see the stimuli, how will it affect their ability to make frequency judgments? With the dual task condition, it was hypothesized that overestimation of high frequency words may increase, but estimation of low frequency words will stay about the same. This assumption is based on an idea that low frequency words should not have a false sense of familiarity because they should have more distinct memory traces and would not be activated quickly like high frequency words.

Chapter 2

METHOD

Participants

Participants included 108 undergraduate students at Arizona State University who participated in exchange for partial course credit. All spoke English as their first language, had no history of memory or language problems, and had normal or corrected to normal vision.

Procedure

Participants were randomly assigned into one of two conditions: Single Task condition (N=52) or Dual Task condition (N=56). Participants were seated in a quiet room in front of computers and were tested in groups of one to four. All computers were PC compatible with standard monitors. All participants gave informed consent and were assigned a subject number. Stimulus presentation and response recording were controlled using E-Prime, an experimental software program (Psychological Software Tools 2002). The task type (Dual vs. Single Task) was a between-subjects variable, word frequency (high vs. low) was a within-subjects variable.

All participants completed a verbal recall task to confirm intact verbal memory. They were shown 24 words presented for 1000ms each. Later, they were given a recognition test. In the recognition test, words were presented one at a time and participants indicated if it was presented before by pressing either YES or NO labeled over the P and Q keys on a keyboard.

To verify adequate math skills, participants completed a math task. They were shown simple two-step math questions (e.g., Does (8 X 2) – 6 = 10?) and they responded by indicating YES or NO on the labeled keyboard.

Frequency Judgment Task

In the study portion, words were presented one at a time and participants were asked to remember them. Words were presented in the middle of the screen in 28 point black font with a white background for 1000ms each. Words in the frequency judgment task were all content words (nouns, verbs, or adjectives) three to six letters in length. Words were categorized as low or high frequency based on their printed word frequency; low frequency was a score of <10 and high frequency was a score of 300 or higher (Kucera & Francis, 1967). See Appendix A for full list of stimuli. In the Dual task condition, participants answered the same type of math problems as those shown in the math task, but they were interleaved with the study words. Participants were presented with one word, responded to a math problem, and were then shown a subsequent word. In the study portion, there were 48 words shown; 24 words (12 high frequency and 12 low frequency) were shown two times and 24 words (12 high frequency and 12 low frequency) were shown four times. The words were counterbalanced between the two repetition conditions.

All participants completed a digit re-ordering task, which also served as a distractor task. In this task, digits were shown one at a time on the computer monitor for one second each. At a prompt, participants typed in numbers in ascending order. Span lengths ranged from three to eight digits, with two trials at each span for a total of 12 trials.

In the memory task, participants were presented with 96 words in 22 point black font. The words were presented one at a time for nine seconds or until the participant responded. All of the study words were shown plus 48 new words (24 low frequency and 24 high frequency). Participants were told to be accurate, but also to respond as quickly as they could. They were not given feedback on their responses. Participants indicated how many times each word was shown in the study task by pressing the corresponding key: 0 times, 2 times, or 4 times (the b, n, or m key on the keyboard, respectively).

All participants completed the Operation Span Task. On each trial, participants saw a two-step math problem (e.g., Does (8 X 2) – 6 = 10?). They responded YES or NO by pressing a labeled key on the keyboard and received feedback. They were then shown a to-be-remembered word. The math-word pairs continued until a recall message, "RECALL THE WORDS" prompted participants to recollect words in serial order and record their written responses in a response packet. Participants were presented a four-word span practice trial and were provided two trials at each span length (two to seven words).

Scoring

Responses were listed in an Excel spreadsheet and separated into low frequency and high frequency words for each participant. Participant's responses were compared to the actual number of presentations and the results were entered into an Excel spreadsheet. The following nine response types included correct responses, misses, underestimations and overestimations. In a correct response, a participant correctly identified the number of presentations (e.g., participant responded that the word was shown two times and it was in fact shown two times, or participant responded that the word was shown four times and it was in fact shown four times). Responses were categorized as misses when participants incorrectly identified words as new (e.g., Participant responded that the word was presented “0” times and it was actually shown two times or four times). Responses were categorized as an underestimation when participants responded that the word was shown two times and it was actually shown four times. If a participant indicated a higher number of presentations than was correct, it was categorized as an overestimation (e.g. Participant responded that the word was shown two or four times and it was actually a new word or a participant responded that the word was shown four times and it was actually shown two times).

For the Single Task (ST) frequency judgment condition, 7054 responses were categorized into correct or error response types and for the Dual Task (DT) frequency judgment condition (requiring calculations) 5280 responses were categorized. The total number of each response type was totaled in a frequency chart (See Appendix B).

The OpSpan task was scored according to the standards outlined in Unsworth and Engle (2007). For each participant, three estimations of operation span were calculated: Total words recalled regardless of order (AllRec), Total words recalled in order (AllOrder), and An all or nothing score (Absolute). The proportion correct (PropRedc) was calculated as AllRec/Total words in list and the proportion of the order correct (PropOrder) was calculated as AllOrder/Total words in list.

Chapter 3

RESULTS

Overall analyses were conducted on the accuracy rates and mean correct response times (RTs) for studied words. Data were analyzed using a 2 (Task Condition: Single vs. Dual Task) X 2 (Word Frequency: High or Low) X 2 (Repetitions: 2 or 4) Mixed Factor Analysis of Variance (ANOVA). Post-hoc t-test comparisons were assessed with a Bonferroni corrected alpha = .017.

The main effect of repetition was significant, $F(1, 105)=7.07$, $p=.009$, $\eta^2=.063$): Two repetition words had significantly higher accuracy than the four repetition words. The main effect of Frequency on accuracy was significant ($F(1, 105)=47.90$,, $p<.0001$, $\eta^2=.313$). Response accuracy to low frequency words was higher than to high frequency words. The main effect of Task condition was only marginally significant ($F(1, 105)= 4.17$, $p=.05$, eta=.040). The interaction between Frequency and Task was not significant ($F<1$), however, the interaction between Frequency and Repetition was significant ($F(1, 105)=10.92$, $p=.001$, $\eta^2=.094$). The four repetition, high frequency condition resulted in significantly lower accuracy than all other conditions (all $p<.001$). The Repetition X Task interaction was not significant ($F(1, 105)=2.735$, $p=.101$, $\eta^2==.025$). Three-way interaction (Frequency X Repetition X Task) was not significant ($F<1$). Figure 1 shows the mean accuracy rates for all conditions.

An ANOVA conducted on mean correct response times (RT's) revealed a significant main effect of Repetition, ($F(1, 101)=17.29$, $p<.0001$, $\eta^2=.146$) with Four repetition words having faster RT's than Two repetition words. A significant main effect of Frequency was also observed ($F(1, 101)=5.54$, $p=.021$, $\eta^2=.052$) with faster RT's to low frequency words compared to high frequency words. There was no significant main effect of Load ($F<1$) and no significant interactions (all $F<1$). Mean correct response times for all conditions are shown in Figure 2.

A 2 (Task) X 2 (Frequency) Mixed ANOVA was performed on the new words (words not shown in the study task). A significant main effect for accuracy on frequency was present ($F(1, 105)=46.47$, $p<.0001$, $\eta^2=.307$) with higher accuracy rates for low frequency words relative to high frequency words. There was no significant effect of Load ($F<1$) and no significant interaction ($F(1, 105)=3.36$, $p=.07$, $\eta^2=.031$). Reaction times were also analyzed and a significant main effect of RT's on Frequency was also observed ($F(1, 104)=6.50$, $p=.012$, $\eta^2=.059$). Low frequency words had faster RTs than high frequency words. There was no significant effect of Load and no significant interaction (both F's < 1). This finding is consistent with previous studies showing better rejection of low frequency distracters than high frequency distracters (Balota, Burfess, Cortese, & Adams, 2002).

Figure 1: Mean Accuracy Data for Frequency Judgments

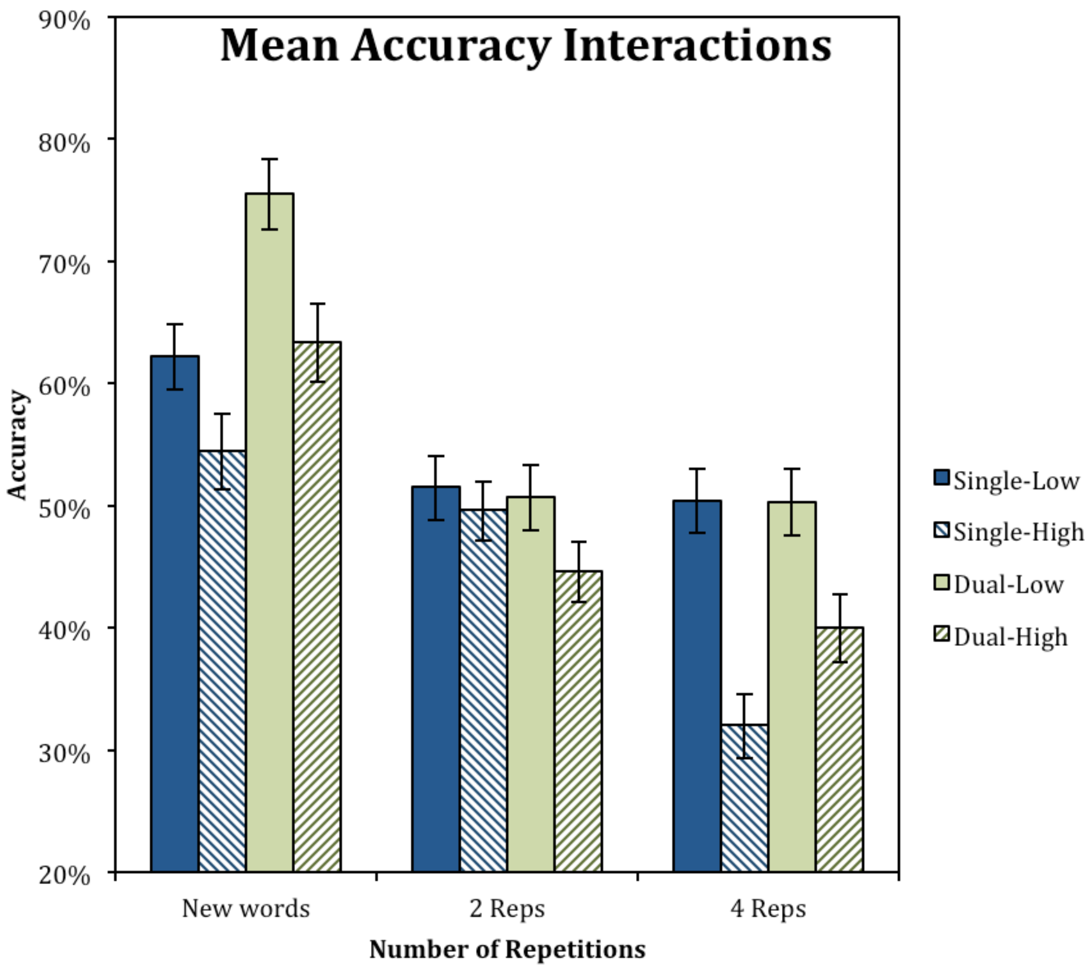
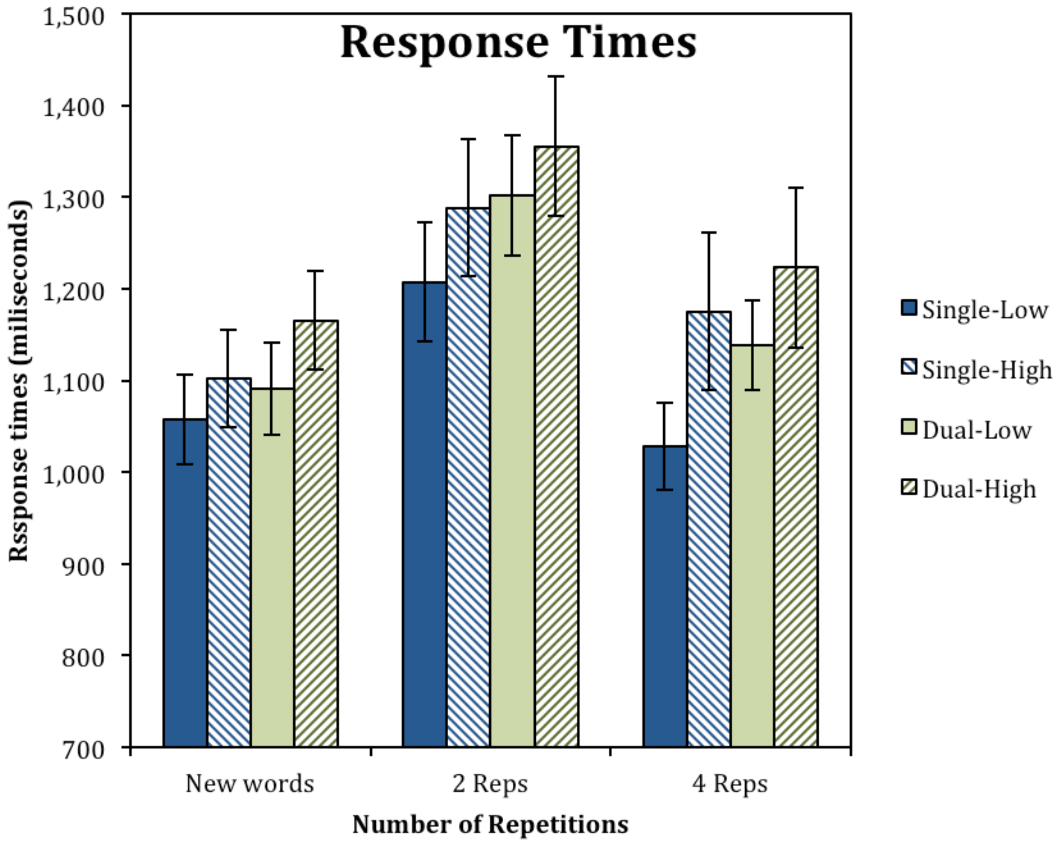


Figure 2: Correct Mean Response Times for Frequency Judgments



Correlations with Working Memory Span

Pearson Correlation analyses were used to examine the possible relationship between WM span and frequency judgments. Error analysis data for the Single and Dual Task conditions were analyzed separately. In the Single Task condition, there was only one significant correlation: WM span was negatively correlated with accuracy for High Frequency words in the Two Repetition condition. In the Dual Task condition, there were no significant correlations between WM span and frequency judgment accuracy. Table 1 shows the results of the correlation analyses between WM and frequency judgment accuracy.

Multinomial Tree Analysis

The overall accuracy analyses only provide information regarding about the correct frequency judgments (correct response or not). However, it could be the case that the person remembered the item, but did not remember how often it was shown. Multinomial tree analyses (Dodson, Prinzmetal, & Shimamura, 1998) hold advantages because they can provide a measure of item memory (i.e. Do they remember the item as old?) as well as a measure of source memory (i.e. In what context did they see the item?). In the current study, this source memory would serve as a measure of frequency memory. Thus, multinomial tree analyses were conducted to examine item memory and frequency memory for low and high frequency words between the different study task conditions.

The memory parameters were calculated based on the actual number of responses and the probability of responses across different response outcomes (Dodson, Prinzmetal, & Shimamura, 1998). Figure 3 shows tree diagrams for the multinomial model used for the high frequency words, low frequency words, and new words. The complete sets of values for the multinomial tree analyses are presented in Appendix C. The parameter estimates for high and low frequency words across Single and Dual task conditions are presented in Table 2. For the item and frequency memory parameters, higher values are associated with stronger memory.

Item Memory

Item memory reflects whether the person remembers the word as being in the study task (regardless of repetition). The multinomial analyses showed that strength increased with more repetitions (i.e. Four repetitions is consistently higher than two repetitions). Item memory strength also appears to be greater for low frequency words over high frequency words. Low frequency advantage is consistent with what was observed in the accuracy analyses. Study task condition (single vs. dual) did not appear to impact item memory.

Frequency Memory

Frequency memory reflects the memory for number of previous presentations. They multinomial analysis revealed that frequency memory for words repeated two times is extremely weak with values at zero, or basically chance. However, effects of study task and word frequency differences were apparent for words presented four times. In the single task condition, there was a much stronger frequency memory for high frequency words relative to low frequency words. In the dual task condition, frequency memory was stronger for low frequency words relative to high frequency words. Overall, frequency memory for high frequency words was stronger in the single task condition than the dual condition.

Error Analysis

The data were further analyzed to examine the type of error responses provided by participants. For each subject, the proportion of each response type was calculated by dividing the number of that response type by the total number of responses.

Two Repetition Condition

Error Responses included misses (participants said the item was new, but it was presented twice) and overestimations (participants said the item was presented four times, but it was presented twice). Planned comparisons t-tests were used to look for differences between task conditions (single vs. dual) and word frequency (high vs. low). Participants in the single task made more overestimations of high frequency words than participants in the dual task ($t(105)=2.06$, $p=.046$). High frequency words resulted in higher miss rates than low frequency words ($t(106)=-4.835$, $p<.0001$) and low frequency words had a greater overestimation rate than high frequency words ($t(106)=3.157$, $p=.002$) . Figure 4 shows the mean proportion of each error type for high and low frequency words in the two repetition condition.

Four Repetition Condition

Error Responses included misses (participants said the item was new, but it was presented four times) and underestimations (participants said the item was presented two times, but it was presented four times). Planned t-tests were used to examine possible differences between task conditions and word frequency. The only significant difference between the two task groups was in the underestimation of high frequency words ($t(105)=-2.30$, $p=.023$). Participants in the dual task made proportionally more underestimations of high frequency words than participants in the single task. High frequency words resulted in significantly higher Miss rates, ($t(106)=-6.37$, $p<.0001$) and higher underestimation rates ($t(106)=-2.69$, $p=.008$) relative to low frequency words. Figure 5 shows the proportion of each error type for high and low frequency words in the four repetition condition.

Table 1:
Correlations Between Frequency Judgment Accuracy and WM Span

		Single Task	Dual Task
New Words – Low Frequency	Pearson Correlation	.049	.008
	Sig. (2-tailed)	738	.957
New Words – High Frequency	Pearson Correlation	.135	-.040
	Sig. (2-tailed)	.351	776
Two Repetitions – Low Frequency	Pearson Correlation	.113	.048
	Sig. (2-tailed)	.437	..734
Two Repetitions – High Frequency	Pearson Correlation	.039	.073
	Sig. (2-tailed)	.786	604
Four Repetitions – Low Frequency	Pearson Correlation	-.100	-.135
	Sig. (2-tailed)	.492	.337
Four Repetitions – High Frequency	Pearson Correlation	-.345*	.170
	Sig. (2-tailed)	.014	.224

Note: N=56 for Single Task; N=51 for Dual task. *Significant positive correlation ($p < .05$)

Figure 3: *Schematic Tree Diagrams for Multinomial Tree Analysis*

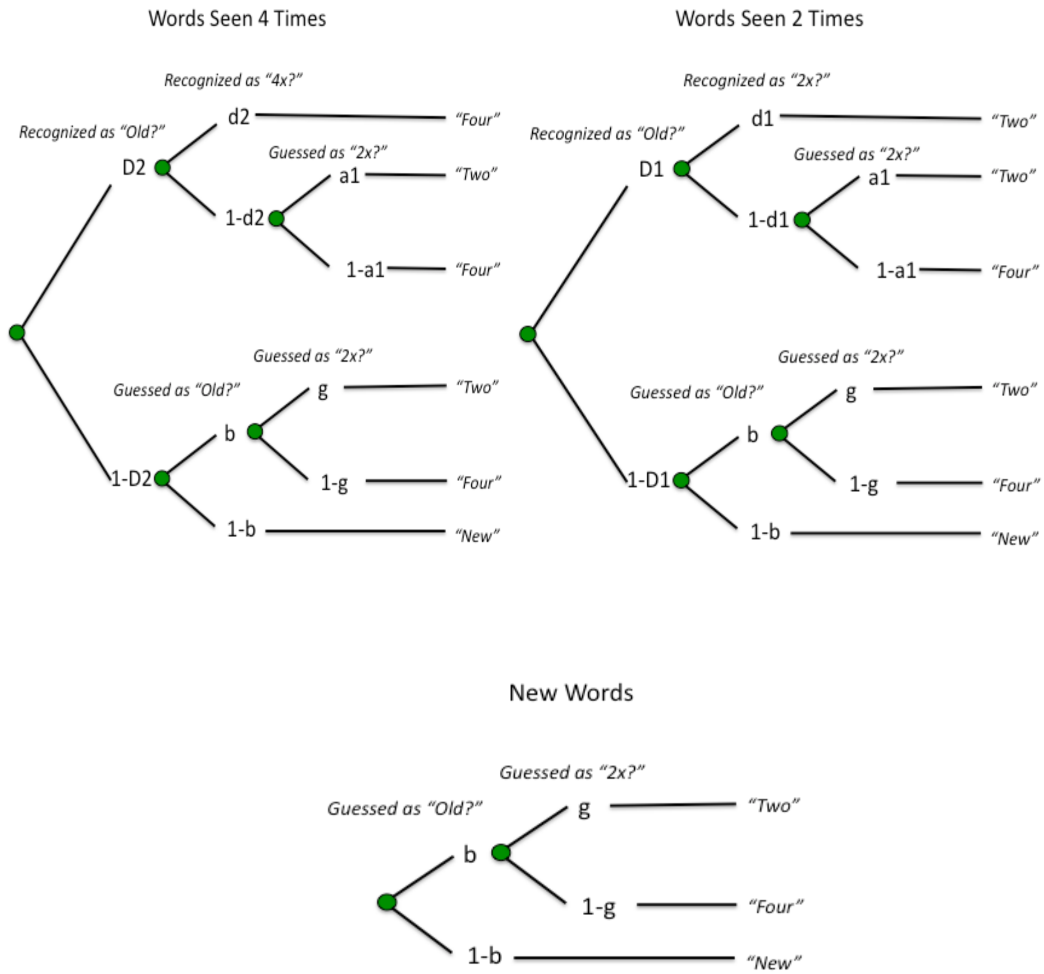


Figure 4: Mean proportion of each response type for high and low frequency words in the two repetition condition.

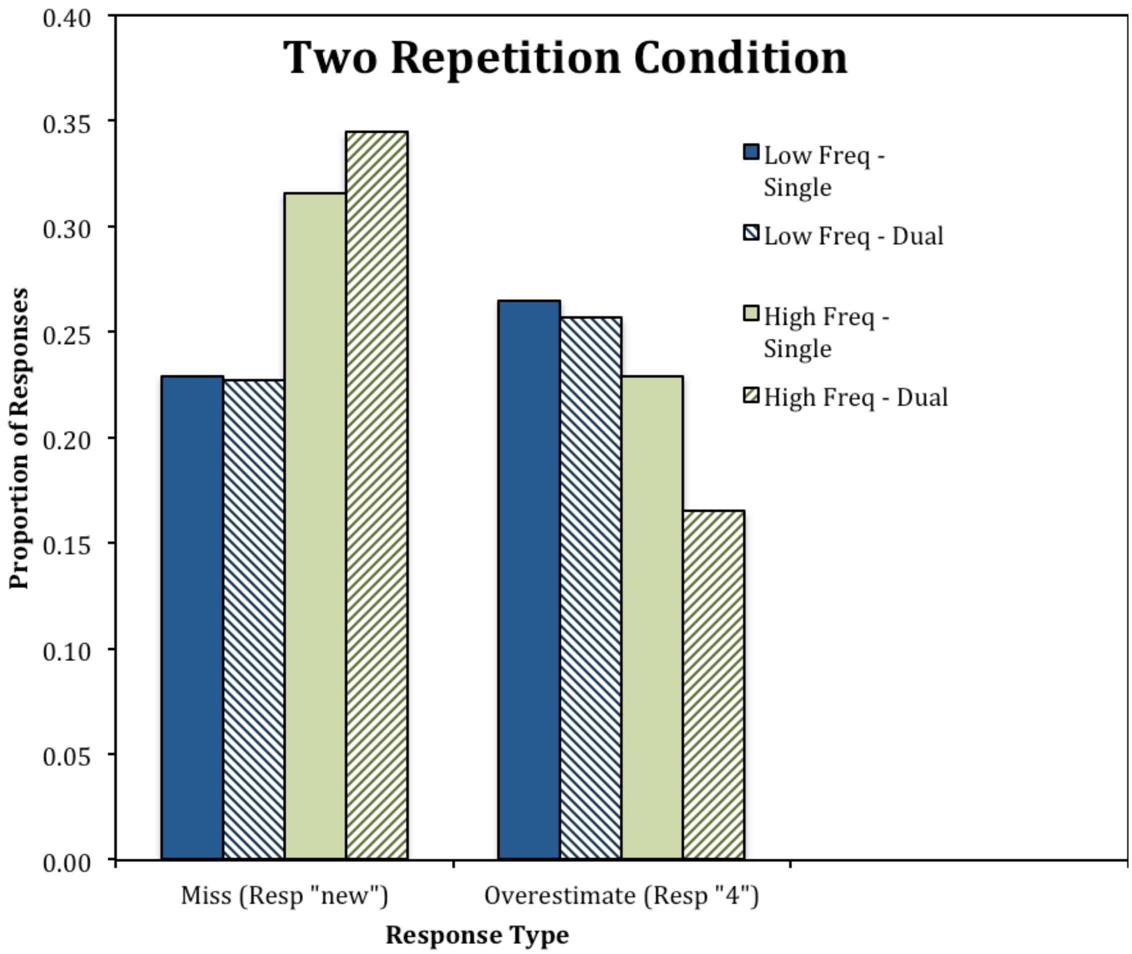
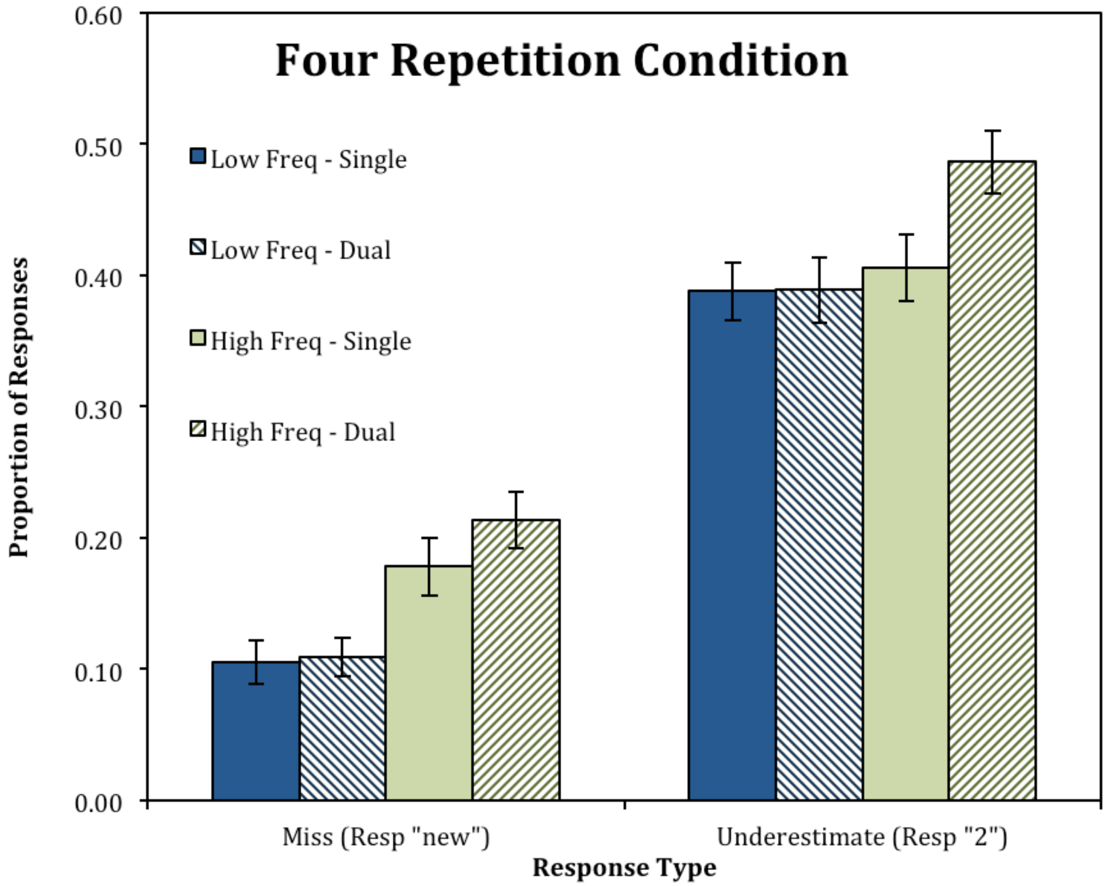


Figure 5: Mean proportion of each response type for high and low frequency words in the four repetition condition.



Misses

A mixed factor 2 (Repetition) X 2 (Frequency) X 2 (Task) ANOVA was performed on the mean proportion of miss responses. There was a significant main effect of Frequency ($F(1, 105) = 55.20$, $p<.0001$, $\eta^2=.345$) with more Miss responses to high frequency words relative to low frequency words. Also, there was a significant main effect of Repetition ($F(1, 105)=148.58$, $p<.0001$, $\eta^2=.586$) resulting in more Miss responses for Two repetition words relative to Four repetition words. No other significant effects or interactions (All F's <1).

Correlations with Working Memory Span

Pearson Correlation analyses were performed to examine the possible relationship between WM span and error responses. Error analysis data for the single and dual task conditions were analyzed separately. In the single task condition, there were no significant correlations between WM span and any of the error types (Misses, Overestimations, and Underestimations). In the dual task condition, there was a significant positive correlation between WM span and overestimation responses for high frequency words in the two repetition condition. Interestingly, the people with higher spans were more likely to overestimate how often high frequency words were presented, see Table 3: Error Analysis - Correlations Between Error Type and WM Span.

Table 2:
Parameter Estimates for the Multinomial Tree Analysis for Single and Dual Task Conditions

	Single Task		Dual Task	
	High Frequency Word Values	**Low Frequency Word Values**	**High Frequency Word Values**	**Low Freque ncy Word Values**
D.1 (Item memory for 2 rep words)	0.476	0.679	0.403	0.682
D.2 (Item memory for 4 rep words)	0.605	0.851	0.652	0.848
ld.1 (Frequency memory for 2 repetition words)	0.000	0.000	0.000	0.000
ld.2 (Frequency memory for 4 repetition words)	**0.728**	**0.436**	**0.282**	**0.429**
a (Probability that they guess "2" times)	0.748	0.727	0.806	0.742
g (Probability that they guess "4"times)	0.748	0.727	0.806	0.742
b (Response Bias)	0.393	0.278	0.407	0.327

Note: For D.1, D.2, Id.1, and Id.2, higher values reflect stronger memory

Table 3:
Error Analysis - Correlations Between Error Type and WM Span

Responses		Single Task	Dual Task
Low Freq. Two Reps Miss	Pearson Correlation	-.169	.024
	Sig. (2-tailed)	.213	.869
High Freq. Two Reps Miss	Pearson Correlation	-.114	-.252
	Sig. (2-tailed)	.403	.075
Low Freq. Two Reps Overestimate	Pearson Correlation	.017	.080
	Sig. (2-tailed)	.898	.579
High Freq. Two Reps Overestimate	Pearson Correlation	.130	.295*
	Sig. (2-tailed)	.341	.036
Low Freq. Four Reps Miss	Pearson Correlation	-.228	-.045
	Sig. (2-tailed)	.091	.754
High Freq. Four Reps Miss	Pearson Correlation	-.051	-.034
	Sig. (2-tailed)	.707	.813
Low Freq. Four Reps Underestimation	Pearson Correlation	.029	-.068
	Sig. (2-tailed)	.835	.636
High Freq. Four Reps Underestimation	Pearson Correlation	-.194	.054
	Sig. (2-tailed)	.151	.707

Note: N=56 for Single Task; N=51 for Dual task. *Significant positive correlation ($p < .05$)

Chapter 4

DISCUSSION

In regards to attention, we were interested in whether splitting attention and word frequency affect the ability to monitor and accurately report frequency information. Also, we predicted that WM span would correlate with better frequency judgment as the task is expected to require aspects of WM processing. In this study, participants demonstrated improved recall for less frequent words. Low frequency words may be more distinct and easier to track relative to high frequency words. This may result in higher accuracy for frequency judgment for the low frequency words. This is consistent with the mirror effect observed in previous recognition tests (Glanzer & Adams, 1985).

In regards to WM, we predicted that high span individuals would perform better than low span individuals, especially in the more demanding dual task condition. However, there were almost no significant correlations between WM span and frequency judgment accuracy. The one significant correlation was unexpected: In the single task condition, WM span was negatively correlated with accuracy for high frequency words in the two repetition condition. People with higher WM actually did worse at judging the frequency of high frequency words in the two repetition condition (although results of the multinomial analysis revealed that frequency memory for all two repetition words was poor).

Multinomial analyses were performed because they provide specific information about item memory and frequency memory. The item memory results were consistent with the overall accuracy results. Study task did not seem to affect item memory and low frequency words had an item memory advantage over high frequency words, consistent with the mirror effect. Surprising effects were observed in the frequency memory results. In the two repetition condition, people showed almost no evidence of any frequency memory (i.e. They could not tell if the word was presented twice or four times). In the single task condition, the four repetition words showed stronger frequency memory for high frequency words relative to low frequency words. Conversely, in the dual task condition, frequency memory for four repetition words was stronger for low frequency words than high frequency words. Overall, frequency memory for high frequency words was stronger in the single task condition than the dual task condition.

It is possible that in the single task condition, participants were better able to encode the presentations of high frequency words in the study task because they were completely focused on the task (not splitting their attention). Additionally, perhaps the high frequency words were better maintained in WM during the study task relative to the low frequency words. Previous studies looking at word frequency in span tasks have found that high frequency words are better maintained in WM (Baddeley & Scott, 1971; Engle, Nations, & Cantor, 1990). If high frequency words are easier to access and to keep activated in WM, each presentation may be better encoded and more easily accessed for retrieval. The combination of these two explanations would account for the better frequency memory for high frequency words relative to low frequency words and the better frequency memory for high frequency words in the single vs. dual task conditions.

The dual task condition results are more difficult to interpret. Low frequency words resulted in better frequency memory relative to high frequency words. The effect was not due to an improvement for the low frequency words because frequency memory was equivalent in the single and dual task conditions. Instead, the frequency memory for high frequency words was much worse in the dual task condition compared to the single task condition. It is possible that splitting attention during the study task meant that the participants had less attentional resources available to encode frequency. The items would be activated, but not actively maintained as in the single task condition, due to limited resources. Thus, each presentation may not be encoded as strongly with the item. This possibility is consistent with the error analysis showing that participants in the dual task made proportionally more underestimation responses to high frequency words in the four repetition condition. This explanation is, of course, speculative and would require further research.

Different theoretical frameworks can account for the patterns across the two task conditions. Baddeley's model (2000) would assume that, in the single task condition, the easily accessed high frequency words should remain partially activated in the episodic buffer during the study task. This maintenance in the episodic buffer may allow the presentations to be better encoded. In the dual task condition, high frequency words would be less likely to be maintained in the episodic buffer because additional attentional resources are required for the secondary task. Thus, the high frequency words could be encoded into LTM for later recall (item memory), but the frequency of presentation would not be encoded.

Unsworth & Engle (2007) would also account for the results because the single task condition is similar to a standard simple span task (words are shown and the participant must recall them). Items will be held in primary memory until the capacity is exceeded (about four items) and then they will be passed to secondary memory along with information about the presentation context. The dual task condition has the same requirements as the study portion of the operation span task (i.e. they must remember presented words while doing math problems). Items are actively stored in primary memory for less time because the intervening math problems require attention and the attentional shift means that each item would quickly moved into secondary memory. Context information for the item may not be fully specified because of the switching attention. In a later search of secondary memory, the item may be remembered, but not the number of times it was presented.

In previous studies, researchers have shown that high span and low span individuals did not differ in recognition accuracy, but high spans performed better when the memory decisions require fine-grained discrimination (e.g., Did this letter appear in a second set of letters?) (Conway & Engle, 1994; Oberauer, 2005). This pattern is consistent with the results of this study. No differences were observed in item memory between single and dual task conditions, but significant differences were observed in frequency memory, which requires more discrimination.

Error analyses revealed that high frequency words had higher Miss rates than low frequency words in both repetition conditions (two and four). Responses were deemed as a Miss if participants indicated a word was new when it had actually been presented (two or four times). This result is consistent with the idea that low frequency words are more distinct and therefore easier to recall. In the two repetition condition, high frequency words were more likely to be overestimated, but, in the four repetition condition, high frequency words were more likely to be underestimated.

Overall, the experiment produced interesting results that were relevant to theories of working memory and episodic memory. Further investigation is warranted to investigate the role of WM and word frequency and how they interact in memory processing for items and their surrounding contexts.

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APPENDIX A

HIGH AND LOW PRINT-FREQUENCY WORD LIST

High Frequency Words

Word/Frequency/Old or New

water	high	old
school	high	old
light	high	old
better	high	old
group	high	old
white	high	old
open	high	old
social	high	old
house	high	old
case	high	old
head	high	old
order	high	old
kind	high	old
room	high	old
city	high	old
place	high	old
young	high	old
matter	high	old
power	high	old
later	high	old
point	high	old
best	high	old
found	high	old
side	high	old

away	high	new
both	high	new
church	high	new
early	high	new
fact	high	new
family	high	new
give	high	new
going	high	new
work	high	new
back	high	new
large	high	new
life	high	new
mind	high	new
night	high	new
part	high	new
people	high	new
state	high	new
second	high	new
sense	high	new
state	high	new
system	high	new
three	high	new
united	high	new
year	high	new

Low Frequency words

Word/Frequency/Old or New

noun	low	new
duel	low	new
apron	low	new
bloat	low	new
bran	low	new
carve	low	new
clumsy	low	new
dangle	low	new
dial	low	new
evade	low	new
faulty	low	new
foul	low	new
gasp	low	new
prop	low	new
plaza	low	new
lash	low	new
leaky	low	new
nylon	low	new
option	low	new
pivot	low	new
rabid	low	new
loft	low	new
tangle	low	new
thaw	low	new
germ	low	old
vest	low	old
wilt	low	old
blur	low	old
hearth	low	old
raft	low	old
stale	low	old
mural	low	old
armor	low	old
poach	low	old
curd	low	old
donor	low	old
nudge	low	old
flask	low	old
gutter	low	old
exile	low	old
barge	low	old
tardy	low	old
boast	low	old
cavern	low	old
pier	low	old
hedge	low	old
knack	low	old
soot	low	old

APPENDIX B

FREQUENCY TABLES FOR SINGLE AND DUAL TASKS

Frequency Tables for FJTask1 (Single Task)

Low Frequency Words

	Actual Presentation			
		0	**2**	**4**
Subject Response	**0**	792	126	60
	2	319	309	233
	4	65	153	295

High Frequency Words

	Actual Presentation			
		0	**2**	**4**
Subject Response	**0**	697	208	121
	2	404	288	288
	4	75	92	177

Frequency Tables for FJTask3 (Dual Task)

Low Frequency Words

	Actual Presentation		
	0	**2**	**4**
Subject Response			
0	953	153	71
2	306	329	250
4	61	178	339

High Frequency Words

	Actual Presentation		
	0	**2**	**4**
Subject Response			
0	801	210	120
2	429	296	261
4	90	154	279

APPENDIX C

VALUES CALCULATED FOR MULTINOMIAL TREE MODEL ANALYSIS

Single Task Condition

Low Frequency Words

Source	Response	Observations	Actual	Pred Prob	G-Squared
Two Times	p("Two")	329	0.498	0.558	-74.351
	p("Four")	178	0.270	0.210	88.959
	p("New")	153	0.232	0.232	-0.001
Four Times	p("Two")	250	0.379	0.379	0.000
	p("Four")	339	0.514	0.514	0.001
	p("New")	71	0.108	0.108	-0.001
New	p("Two")	306	0.232	0.202	84.261
	p("Four")	61	0.046	0.076	-60.741
	p("New")	953	0.722	0.722	-0.001
				Total G-Squared:	**38.127**

Single Task Condition

High Frequency Words

Source	Response	Observations	Actual	Pred Prob	G-Squared
Two Times	p("Two")	296	0.448	0.510	-76.246
	p("Four")	154	0.233	0.172	94.494
	p("New")	210	0.318	0.318	-0.001
Four Times	p("Two")	120	0.182	0.240	-66.152
	p("Four")	261	0.395	0.521	-143.880
	p("New")	120	0.182	0.240	-66.152
New	p("Two")	429	0.325	0.294	85.499
	p("Four")	90	0.068	0.099	-67.140
	p("New")	801	0.607	0.607	-0.002
				Total G-Squared:	**-239.580**

Dual Task Condition

Low Frequency Words

Source	Response	Observations	Actual	Pred Prob	G-Squared
Two Times	p("Two")	309	0.526	0.583	-64.422
	p("Four")	153	0.260	0.202	76.774
	p("New")	126	0.214	0.214	-0.001
Four Times	p("Two")	233	0.396	0.396	-0.001
	p("Four")	295	0.502	0.502	0.001
	p("New")	60	0.102	0.102	0.000
New	p("Two")	319	0.271	0.242	71.794
	p("Four")	65	0.055	0.084	-54.630
	p("New")	792	0.673	0.673	-0.001
				Total G-Squared:	**29.514**

Dual Task Condition

High Frequency Words

Source	Response	Observations	Actual	Pred Prob	G-Squared
Two Times	p("Two")	288	0.490	0.521	-35.151
	p("Four")	92	0.156	0.126	40.367
	p("New")	208	0.354	0.354	0.000
Four Times	p("Two")	288	0.490	0.491	-1.963
	p("Four")	177	0.301	0.302	-1.206
	p("New")	121	0.206	0.206	-0.825
New	p("Two")	404	0.344	0.328	37.087
	p("Four")	75	0.064	0.079	-32.466
	p("New")	697	0.593	0.593	-0.001
				Total G-Squared:	**5.842**