2008

Tactile Working Memory And Multimodal Loading

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TACTILE WORKING MEMORY AND MULTIMODAL LOADING

by

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M.S. University of Central Florida, 2006
B.S. University of Florida, 2000

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Spring Term
2008

Major Professor: Richard D. Gilson

ABSTRACT

This work explored the role of spatial grouping, set size, and stimulus probe modality using a recall task for visual, auditory, and tactile information. The effects of different working memory (WM) loading task modalities were also examined. The Gestalt spatial organizing principle of grouping showed improvements in response times for visual and tactile stimulus probes with large set sizes and apparently allowed participants to effectively chunk the information. This research suggests that tactile information may use spatial characteristics typically associated with visual information, as well as sequential characteristics normally associated with verbal information. Based on these results, a reformulation of WM is warranted to remove the constraints of the input modality on processing types. The input modalities appear to access both a spatial sketchpad and a temporally-based sequence loop. Implications for multisensory research and display design are discussed.

I dedicate this to my wife, Jessica, for understanding and supporting me throughout the entire process.

ACKNOWLEDGMENTS

I would like to thank Drs. Richard Gilson, Edward Rinalducci, Jessie Chen, Valerie Sims, and James Szalma for all of their valuable insights and support. I must also thank my fellow students that were going through this process with me. Your openness to questions, discussions, and airing of frustrations is deeply appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

CE	Central Executive
EAI	Engineering Acoustics, Inc.
LTM	Long Term Memory
LTS	Long Term Store
PL	Phonological Loop
STM	Short Term Memory
STS	Short Term Store
VSSP	Visuo-spatial sketchpad
WM	Working Memory

CHAPTER ONE: INTRODUCTION

Today, increased technological sophistication provides unparalleled access to information for the user. Computer applications and the content of World Wide Web pages continue to leverage increases in processing power, available memory, and communication bandwidths. Utilizing these technological advances, interface designers employ multiple sensory inputs to communicate additional content (Sarter, 2006; Oviatt, 2002). Therefore, the design question in this increasingly complex human/system interaction must focus more on the user's information processing abilities and constraints. One such constraint is memory capacity, including the related issue of how the user represents multi-sensory information in memory. If the user is bombarded with multi-sensory information, it is important to understand not only how the user represents this information in memory, but how the user extracts and utilizes this content in a typical multi-tasking environment. The focus of this work is to examine the ability to extract multimodal information from memory, as this type of presentation is increasingly popular in education and training (Mayer & Moreno, 2003).

This experiment will employ unisensory memory cues to retrieve this information, while under concurrent memory demands. Memory recall often does not happen in a task demand vacuum, and additional memory loads may exist in the multi-tasking environments of many human-machine system users. One portion of this experiment will use unstructured multimodal information (i.e., no spatial grouping) under secondary task constraints. The second will use spatially-structured information as the material for encoding and retrieval. Spatially-structured information may be more easily encoded based on obvious spatial factors, and may therefore show reduced interference with concurrent memory loads (Breuker, 1984).

The experimental paradigm Saul Sternberg developed while working at Bell Laboratories will be used for this research. Many of his memory experiments provide excellent and implementable mechanisms for addressing the relevant factors in this work. In his now classic 1966 study, Sternberg showed experimentally the time it takes to scan short-term memory, now typically designated as working memory (WM; Baddeley & Hitch, 1976; Baddeley, 2001). The Sternberg *recall* task (differentiating it from the *recognition task*) required the participant to learn a short list of items (numbers or letters, presented either visually or aurally). The experimenter then presented a visual memory *probe* stimulus (one of the visual set members). The probe stimulus served as the retrieval marker, and the participant responded with the member of the set that followed the probe stimulus. Sternberg found that response times increased linearly as the memorized set size increased. This same response time relationship was found for auditory stimulus sets and their respective auditory memory probes. Sternberg concluded that participants were performing a serial search of the memorized set, as a parallel search of the data would have not shown linear response time differences with increased set sizes.

Chi and Chase (1972) used this experimental procedure with an interesting modification. In their recall experiment, the probe stimulus was not presented in the same sensory modality as during memorization. A visual set would therefore have an auditory stimulus probe instead of the visual probe (and vice versa). To clarify, a visually presented set of letters “M, K, L, X” would have an verbally presented “L” as a stimulus probe, and the participant would have to respond with the correct answer, “X.” Chi and Chase used the traditional Sternberg recall task to serve as a baseline for comparing the results of matched set/probe for modality and mismatched set/probe for modality. The results of this experiment showed that it required an average of 40 ms longer to search for an item in memory when a mismatched modality probe was used. One potential explanation for this is that it takes time to actively convert the stimulus probe into the same modality code as the memorized list. This would only need to be done once during the scanning procedure, and this modified probe could then be used as a comparator during serial list scanning. There is additional evidence to support this rationale. Sternberg (1966; 1969) found that degraded stimulus probes (incomplete letters) required a fixed amount of additional time to complete the serial scanning procedure. He posited that the extra time was necessary to mentally complete the letter, and to then continue with the scanning task with the completed figure as the comparator. This amount of time is small, but it is consistent. The increase is likely due to the level of letter degradation (Sternberg, 1969). For Chi and Chase's experiment, the additional small amount of time required can be attributed to the high degree of association between the verbal and visual stimuli.

These findings suggest that this experimental paradigm can include tactile stimuli as well as visual and auditory stimuli. The recall task can be modified to present a series of multisensory sequences, consisting of corresponding visual, auditory, and tactile stimulus elements. Multimodal information typically strengthens encoding (Mayer and Moreno, 2003), therefore the lists were presented using all three modalities. Current neurophysiological data demonstrates the existence of bimodal as well as trimodal neurons (i.e., neurons that respond to either two or three sensory inputs that overlap sufficiently in time and/or space; Grazziano, Gross, Taylor, and Moore, 2004). These findings offer a potential neural substrate for the strengthening of encoding through multisensory engagement.

Unisensory probes will determine the interplay of working memory components (Baddeley & Hitch, 1974) during concurrent secondary demands during recall. Accuracy and latency from the Sternberg recall task will serve as a measure of unisensory access to multimodally encoded information. In previous experiments with aural and visual letter presentation, the user became very familiar with these information formats and therefore requires little time to switch modality codes. In a contemporary setting, tactile signals can be accurately modeled from existing visual signals (e.g., U.S. Army arm and hand signals; Redden et al., in press); however, we are often not as familiar with tactile stimuli and their visual correlates. It is reasonable to hypothesize that in the Chi and Chase version of the Sternberg recall task paradigm, additional time would be needed to search a memorized list of tactile, auditory, or visual sequences if the degree of association between the two modality codes was low.

The modality of the probe can then be contrasted with concurrent WM component loadings, thereby assessing the involvement of WM components during the retrieval process. The implication of this finding is potentially vital for multimodal display systems. For the original Sternberg task, well-learned numbers and letters were used, but they were also well-learned across vision and audition. A visual “T” corresponds strongly with an audible “T.” The question then becomes how participants will respond with this task using a multimodal display that incorporates visual, verbal, and tactile information.

Additionally, structuring the memorized information into discrete units may alleviate this problem during concurrent demands, assuming the resources necessary for structuring do not exceed the total available during concurrent tasks (Kahneman, 1973; Wickens, 1984; Allen, Baddeley, & Hitch, 2006; Mayer & Moreno, 2003). Using Gestalt principles to spatially structure informational groupings is standard practice in visual display design (Sanders & McCormick, 1993). However, these spatial organizing principles are not often applied to somatosensory displays. Some recent exceptions are in the area of haptic displays, examining the effects of surface differences on participant grouping of haptic displays (Chang, Nesbitt, Wilkins, 2007). Interestingly, their results showed that there is a strong concordance between those factors affecting visual grouping and haptic grouping. Building upon these findings, it may be reasonable to assume that performance differences may exist between unstructured and structured memory items for passive somatosensory displays, as well as other displays that rely on spatial perception factors. Memory research consistently points to the reconstruction-based nature of memory as opposed to the running video record. Recollection differences are often found due to leading questions during accident investigations and trial testimony (see Loftus, 1975). Leveraging a Gestalt spatial proximity grouping principle as a memory guide may provide a multisensory memory mnemonic, allowing recollections of additional material. Mnemonics are powerful memory tools (see Reed, 2007), and Gestalt principles may represent a memory reconstruction guide that exists at an almost fundamental level in human cognition (Breuker, 1984). While most mnemonics must be actively trained, Gestalt spatial organizing principles may arise in human neural networks as a result of the input/output interactions with the environment. Leveraging these may alleviate memory loads across sensory modalities, and allow improved task performance during concurrent memory loads within and across WM systems.

The spatially ungrouped stimuli in the experiment will determine the scanning time for multisensory information based on unisensory memory probes for cued retrieval. The multisensory information will consist of two set lengths, but all of the information is spatially unstructured (ungrouped, with no distinct units). Concurrent WM loads will ascertain the relative independence of the unisensory pathways for accessing multimodally-encoded content. In the spatially grouped condition, the multimodally-encoded information is structured so that it utilizes spatial factors to group the information into distinct units. This may aid in recall, perhaps in a differential fashion under disparate WM component loadings.

CHAPTER TWO: LITERATURE REVIEW

Memory Models

Memory Distinctions

Numerous texts ascribe distinctions to various aspects of memory. For example, they delineate memory into explicit versus implicit, episodic versus semantic, and short-term versus long-term (Reed, 2007). Another set of prominent distinctions is found in the stages of memory. The *process* of memory is typically divided into the tasks of encoding, storage, and retrieval (Melton, 1963) for long-term storage. Encoding is the transfer of information into memory, storage is the retention of that encoding, and retrieval is the extraction of information from memory. This work focuses on the short-term versus long-term memory distinction, and its more recent evolutions that will be discussed in upcoming sections.

Atkinson & Shiffrin Box Model

One of the most successful and influential models of cognitive processes was the “box model” developed by Atkinson and Shiffrin (1968). This model proposed distinct stages for incoming sensory information, short-term storage (STS; or short-term memory [STM]), and long-term storage (LTS; or long term memory [LTM]). Information would be transferred from the sensory buffer to the STS, and a rehearsal mechanism would facilitate the transfer of information from STS to the quasi-permanent LTS. Memories can also be drawn from the LTS into STS to aid in current processing needs.

Considerable evidence supported this delineation of memory stages, as each was shown to have its own unique properties. Sensory information is lost rapidly if it is not attended to and transferred into the STS. The information in STS also decays, though not as rapidly as in the sensory buffer. Rehearsal is necessary in order to prevent degradation and to transfer it to LTS. Information in LTS is considered to be quasi-permanent, with LTS difficulties stemming more from problems in retrieval and not memory degradation over time. Research on memory tasks often yields a serial position curve, showing that items memorized early in the sequence (primacy effect) and at the end of sequence (recency effect) are more likely to be recalled than those items learned in the middle of the sequence (Reed, 2007). The interposition of additional tasks at these different memory task stages indicated rehearsal supports the transfer of early items in to LTS. Suppressing rehearsal at the end of sequence encoding task also showed that rehearsal was necessary to transfer the last items into memory (Peterson & Peterson, 1959; Postman & Phillips, 1965). It is also important to note the capacity differences between STS and LTS. STS is potentially limited to 5-9 items (Miller, 1956), depending upon the nature of the item(s). The key point is that STS is limited, though no functional limit exists on the LTS (Robinson-Riegler & Robinson-Riegler, 2004).

Baddeley's Working Memory Model

While the box model did account for a significant amount of experimental findings, it did not explain differential performance in many dual-task experimental paradigms. Baddeley reformulated STM into a multi-component system for actively processing information. The initial design of the WM model had three key components, specifically the phonological loop (PL), the visuo-spatial sketchpad (VSSP), and the central executive (CE; Baddeley & Hitch, 1974; Baddeley, 1986). The PL allows the maintenance and processing of acoustic/verbal information in WM, while the VSSP allowed the maintenance and processing of visual spatial information. These two components were considered subservient systems of the CE, which controls the allocation and time-sharing of activities between the PL and the VSSP. While various experimental data generally supported the existence of the two sub-systems, identifying the exact nature of the CE as the control mechanism has proven more difficult to ascertain (Baddeley, 2001). Recently, Baddeley (2000) proposed a revised WM model with the addition of the episodic buffer (EB) to account for the growing body of evidence showing the limitations of the tripartite model.

The EB serves as an integrated multimodal workspace between the CE and long-term memory storage. However, even with this addition, the revised model does not fully account for sensory inputs beyond vision and audition. WM in its current form does not address somatosensory information as an input into any current component. Nor does it address its potential for having a dedicated subsystem for information processing and maintenance in memory. Perhaps spatial aspects of tactile information are processed in the VSSP, and readily identifiable tactile stimulations that are easy to verbally label are processed primarily in the PL. Perhaps the somatosensory is its own sub-system that is varyingly independent based on the type of stimulation. Considerable research effort has been brought to bear on the potential independence of somatosensory processing (for a review, see Mahrer & Miles, 2002). However, additional investigations are necessary to determine how this information is processed, either via its own mechanism or recoded within an already identified component of WM.

Representations in Memory

One important characteristic of display design is how retrieve information once the user has encoded and stored it. It is therefore important to consider the implications of retrieval cue modality on encoded information (Chi & Chase, 1972). The differing schools of thought on the nature of memory representations tend to complicate this issue. Many of the arguments can be divided into two primary categories, those that support a dual-coding system (e.g., Paivio, 1971; 1990; as cited in Reed, 2007) and those that champion a propositionally coded system (e.g., Pylyshyn, 1973). Under the dual-coding paradigm, information is encoded both as an image and as a propositional code (akin to a set of verbal statements). In the purely propositional paradigm, mental imagery (e.g., picturing your family pet in your mind's eye, the sound of its barking, the feel of its coat) is the result of activation of this code. Mental imagery is therefore a consequence of the code activation, and not encoded independently. This debate sparked considerable research evidence. Much of this accumulated research supports a dual-coding view based on sensory-perceptual processes. One such piece of evidence stems from Shepard and Metzler's (1971) work on mental rotation. They found that the time it takes to rotate a figure mentally increases linearly with increasing angle of rotation. A purely propositional system does not fully account for this finding. Why would people continue to mentally rotate an object through the entire range if a propositional statement putting the figure automatically in the new orientation could be used instead? Additional evidence from mental animation studies supports the dual-coding system (Hegarty, 1992), as additional time is necessary to verify the direction of movement in a system of pulleys as the system's complexity increased. Kosslyn (1995) also summarized the key findings that support a dual-coding system over the use of a propositional system, based upon the limitations of the propositional argument, the demand characteristics of visual scanning experiments, and the neurological underpinnings of mental imagery. While it is difficult to entirely disprove the propositional argument, substantial evidence exists in support of a dual-coding hypothesis.

One common application of the dual-coding hypothesis is in multimedia presentations for learning new material. Sophisticated display technologies can present simultaneous visual and auditory content to the user. For instance, a user can watch an animated diagram of an automobile's powertrain with an accompanying narrative explaining each part as it is highlighted in the presentation. Concurrent presentation of related verbal and visual material engages both aspects of the dual-coding hypothesis, perhaps allowing for a robust coding within memory through deeper processing (Craik & Lockhart, 1971). Perhaps a multi-code system allows for enhanced representations and minimizes cognitive overload (Mayer & Moreno, 2003). Mayer and Sims (1994) found that multimedia learning does benefit the learner during instruction and that presentation through multiple inputs is likely to build connections across those input pathways and subsequent representations. Following the benefits of multimedia presentation and Mayer's methods for reducing the chance for cognitive overload by parsing across subsystems, it may prove interesting to determine the benefits of concurrent a tactile presentation (i.e., a tri-coded system). If the tactile stimulation is meaningful to the learned material, it may help to develop connections with concurrent visual and auditory stimuli, strengthen the level of encoding, and ultimately aid in retrieval. Tailoring the three modalities to work in this tandem fashion has the capacity to significantly improve ease and depth of encoding, as well as facilitate retrieval under demanding conditions.

Role of Attention in Memory

<u>What is attention?</u>

Throughout its history as a subject of theoretical consideration, the concept of attention traversed a unique path from complete understanding ("Everyone knows what attention is"; James, 1890/1950, p. 261; as cited in Fernandez-Duque & Johnson, 2002) to the near nebulousness ("No one knows what attention is"; Pashler, 1998, p. 1). For the purposes of this work, a more open view of attention is applicable. Pashler (1998) referred to the facets of attention as "more general limitations in mental functioning, in making decisions, storing information in memory, planning actions, and so forth (p. 8)." To better understand the role of attention, I will briefly describe the evolution of its dominant formulations, current statuses, and applications to this work.

<u>Filter Theories</u>

Filter theories grew out of considerable research using Cherry's (1953) dichotic listening paradigm (independent auditory signals presented to each ear). The inability to attend to two different streams of auditory information provided the impetus for Broadbent (1958) to formulate a gate-controlled model of attention. To illustrate, imagine a Y-shaped piece of pipeline, with incoming auditory information from each ear arriving at either of the top two branches of the pipe. Attention acted as a selective gateway where the pipes met, essentially closing off information from the unattended channel. Information that passed could then proceed to more advanced processing for comprehension of meaning (for an additional review, also see Proctor and Van Zandt, 1994). Experimental evidence showed that some information could be gleaned from the unattended channel. The gender of the speaking voice could be determined, indicating some frequency analysis. However the meaning was undetectable. This was demonstrated in experiments that required the participants to attend to one ear while both ears were listening to dialogue, and at some point the unattended ear would switch from English to German (same speaking voice). Participants would often not notice the language transition. While this conceptualization of attention proved useful, it could not explain the infamous cocktail party effect, whereby an unattended conversation suddenly springs forth into awareness due to the mentioning of something personally significant. Moray (1959) conducted a series of experiments on this phenomenon and demonstrated that some critical information (e.g., your name, spouse's name, yelling the word "FIRE") was more likely to cause a shift of attention or perhaps bypass the filter blocking the unattended channel. The filter model at that time could not account for these findings until a subsequent modification.

Triesman (1960) put forth the modification, retooling the strict filter model into a new attenuation model. In this reformulation, the unattended channel is merely attenuated, not blocked in its entirety. A lexicon of information with varying thresholds of activation determines entry into consciousness awareness. In the case of Moray's findings and the cocktail party effect, neutral information such as the word "car" may have a high threshold for activation in the unattended channel, but your name has a much lower threshold for activation and can cause the shift of attention to the unattended channel. The thresholds for information are dynamic, allowing contextual information to alter the likelihood of attentional shifts. This model then acknowledges that basic sensory information is still processed, but meaningful processing again only occurs with specific attention. Deutsch and Deutsch (1963) disagreed with this interpretation and stated that meaningful processing still occurred, but attention served to guide only the response to the information, not the majority of its processing. The debate on this is still not entirely complete, as both explanations can often be applied to the same experimental findings.

In addition to the filter theory formulation, researchers have also characterized attention as a spotlight rather than as a filter. In this conceptualization, attention serves as a spotlight, highlighting a portion of the incoming sensory information for in-depth analysis (Sternberg, 2002). This spotlight can be redirected to relevant portions of the scene, depending on the task and the incoming sensory information. The spotlight analogy works well for visual information, and is in many ways analogous to the aurally-based filter theories, particularly Triesman's attenuation model. The reason for this is that the spotlight of attention is actually object-based rather than purely spatially-based in nature. Neisser (1967) cleverly demonstrated this process by presenting two overlapping videos (a visual variant of the dichotic listening task). Even though the videos occupied the same visual space, attention could not be paid to both videos simultaneously. Participants could selectively activate the necessary information in either movie, indicating that top-down (conceptually-driven) information plays a significant role in attentional processes, not just bottom-up (data-driven information from sensory stimulation) information. This finding also supports the results obtained from experiments using the Cherry and Broadbent's dichotic listening experimental paradigm.

Resource Theories

In addition to filter/spotlight theories, attention can also be viewed in terms of a limited resource that must be apportioned to a given task or tasks. Kahneman (1973) conceptualized attention as a limited, unitary mental resource. This resource can be redirected given the current information processing and response demands of the situation. The difficulties in time-sharing multiple tasks does point to a limited capacity system of mental resources, even if the resources themselves have proven difficult to define consistently. Wickens (1984) alters this basic conceptualization to account for dual-task data that is not fully explained under the unitary attentional resource explanation. If mental resources are unitary in nature, then any two tasks that are similarly difficult should yield similar performance decrements during concurrent presentation. However, this is not necessarily the case. Two tasks can often be time-shared in a more effective manner if the tasks differ along several key dimensions, e.g., a verbal task and a spatial task. To illustrate, it is much easier to drive and talk on the phone than it would be to play Tetris and drive, or talk on the phone while speaking with the person next to you. Wickens reformulated the unitary pool of attentional resources into a resource model with multiple, quasi-independent pools. This model posits that task aspects vary along three critical dimensions, namely input modality (auditory/visual), processing type (verbal/spatial), response time (verbal, manual). Generally, the more two concurrent tasks differ along these dimensions, the more they draw from independent resources pools, and are therefore time-shared in a more effective manner. Evidence from dual-task studies often supports this conceptualization of attention (e.g., Brooks, 1967; Logie, Zucco, & Baddeley, 1990). While simultaneous task performance does suffer, those tasks that overlap along these dimensions cause more detrimental interference with one another than those that do not overlap as highly.

A key point to these formulations of attention is that while considerable research has addressed the overlap of primarily visual and auditory tasks, the impact of somatosensory information has not been fully elucidated. If somatosensory information uses independent resources, then it may serve as both another input pathway and another processing area. If it also serves as another input, it may then only produce interference with the visual and auditory inputs during processing for verbal and spatial coding. Clearly, more research is needed in order to ascertain the potential independence of tactile information as an input into human information processing, and also how that information is represented in memory across all the senses for additional processing.

Many studies on memory recall with concurrent tasks indicate the robustness of memory recall. However, concurrent tasks have shown to interfere with cued recall memory tasks (Rohrer & Pashler, 2003). In this study, a concurrent serial choice reaction time task hindered both recall accuracy and recall response times. The authors concluded that secondary task demands were sufficiently high to occupy a limited capacity central processor, thereby interfering with the central processing resources needed to compute the response selection for the cued recall task. However, this study failed to address what may happen to recall if secondary memory loadings for vision and audition are presented. If these temporary memory buffers are occupied by secondary memory loadings, that may hinder recall of information normally used by those same WM subsystems.

Neurological Evidence

Numerous neurophysiological activation studies have been conducted in order to determine the links between perception and mental imagery, e.g., positron emission tomography and electroencephalography. This is a coordinated attempt to understand the neurological coding and representation of information in the brain. Cortical structures have been isolated for the processing of specific sensory inputs. Specifically, areas of the occipital lobe show heightened activation during visual perception, areas of the temporal lobe shows similar increased activation during aural perception, and areas of the parietal lobe show activation during tactual perception. Farah (1988) argues that electrophysiological and neuro-metabolic imaging studies conclusively refute any propositional coding system. In these studies, mental imagery of unperceived visual stimuli shows activation of areas in the occipital lobe typically seen during visual perception. Corresponding evidence exists for auditory imagery (Janata, 2004). In the absence of auditory stimulation, mental imagery of auditory stimuli revealed activations in the auditory cortex that normally responds to auditory perception. This evidence extends to tactile information, with increased activity for areas within the parietal lobe (e.g., Newman, Klatky, Lederman, & Just, 2005).

Crossmodal Research

The aforementioned neurological evidence does suggest that sensory information remains completely separated according to the input modality. Considerable neurological evidence shows the presence of cross-modal neurons and connections to facilitate the representation of mental constructs with multi-modal inputs. One such representation is that of perception of space (e.g., Spence & Driver, 2004; Spence & Driver, 2000). Traditionally, the perception of space was studied using unimodal stimulus paradigms; however, recent evidence suggests cross-modal connections in the perception of space. Cross-modal influences are often seen in phenomena such as the ventriloquism effect, whereby the auditory perception of stimulus origination is shifted due to the visible mouth movements of the puppet and away from the actual ventriloquist. In this case, the visual sense influences the spatial perception derived from audition.

Tactile information has also been found to modulate auditory information, at least in the realm of spatial perception (Caclin, Soto-Faraco, Kingstone, & Spence, 2002). Here, concurrent tactile stimulation to the left or right fingertip could bias the perception of an auditory stimulus emanating from either a right or left speaker. This tactile "capture" of an auditory spatial perception diminished with increasing stimulus onset asynchronies as well as with extended practice in localizing the sound's source. This latter effect establishes that participants were eventually able to disentangle the sound from the vibration, as the spatially incongruent audio-tactile signals did not aid in localization.

In a more applied setting, Ho and Spence (2005) found that spatially predictive auditory cues could significantly affect visual capture times in driving simulations. They examined the use of unreliable spatial auditory cues, reliable spatial auditory cues, and similar verbal cues. While spatial and reliable verbal cues were the most powerful in reducing response times to concurrent visual events, simple verbal (and reliable) cues were also found to speed response times. This work highlights the influence of auditory signals (both spatial and nonspatial) on visual capture.

Ho, Tan, and Spence (2005) also found that vibrotactile cues could significantly speed response time to visual events occurring in front of or behind the participant. Once again, these findings occurred in the more applied setting of an automobile simulator. While this data appeared robust, a subsequent experiment with new visual task showed response decreases for spatial auditory indicators, but not spatial tactile cues (Ho, Tan, & Spence, 2006). While this does muddy the water on the interaction of tactile signals on visual tasks, the authors express the need for additional work to clarify the impact of spatial tactile signals on the cross-modal perception of space.

In support of these cross-modal interactions between vision and audition, researchers have identified neurons that respond strongly to bimodal inputs from visual and aural inputs, as well as visual and tactual inputs (Kandel, 2000). Building on this cross-modal integration, Grazziano et al. (2004) found that several cortical areas are not only responsive to unimodal or bimodal stimuli, but they may actually integrate information derived from vision, audition, and touch. This trimodal integration area in the ventral intra-parietal area may respond best with overlapping spatial fields from the three sensory modalities and thereby allow for an integrated polysensory experience. The issue is further complicated for tactile, as different aspects of tactile stimulation (i.e., frequency, intensity, spatial location) show differential activations within the cortex (Forster & Eimer, 2004). This may suggest cross-modal integration of intra-modal stimulus characteristics, such as the perception of spatial location across modalities, but not other stimulus parameters.

It is likely that multisensory interfaces leverage these cross-modal connections. They permit a multimodal representation of the sensory environment, and this representation likely continues into memory based on the aforementioned neuroimaging similarities found between sensation and mental imagery. Given these inherent connections, multisensory interfaces allow for robust performance and may facilitate lower resource demands and reduced mental workload (for a review, see Cockburn & Brewster, 2005). One issue that is only partially addressed in the cross-modal studies of spatial attention is the ability of visual, auditory, and tactile information to access multimodal representations, particularly under concurrent memory loads that would already activate the necessary cortical representation areas.

Principles of Gestalt Psychology

Gestalt theory, first described in 1910, continues to influence modern trends in psychological thought (Chang & Nesbitt, 2006). Though often formulated as "the whole being greater than the sum of the parts," Gestalt psychological principles were primarily concerned with the organization of stimulus elements into unified perceptions. In this conceptualization, the individual perceives the whole pattern in a manner beyond the individual components. The "gestalt" perception actually serves important purposes in display design. Grouping display elements into coherent patterns is beneficial not only from the aesthetic, "gestalt" sense, but also from the human performance standpoint. Grouping display (and control) elements can reduce response times and prevent errors (Sanders & McCormick, 1993), and many of these design guidelines stem from the Gestalt principles of similarity, balance, continuation, spatial/temporal proximity, etc.

Due to the human perceptual system's ability to extract and group stimulus elements into more complex perceptual structures, Gestalt principles may therefore serve an important function in the chunking of information. Chunking refers to the grouping (or regrouping) of information into new units. Though working memory has a theoretical capacity limit of several items (Miller, 1956; Cowan, Elliot, Saults, Morey, Mattox, Hismjatullina, & Conway, 2005), there are relatively few constraints on the nature of those items. For instance, memorizing the letter sequence “C,I,A,D,H,S,F,B,I,A,T,F,N,S,A” may appear to exceed WM’s inherent capacity. If these units are regrouped based on prior knowledge of US governmental organizations, then the letters are now “CIA, DHS, FBI, ATF, NSA.” The chunked list of items theoretically stays within the capacity limitations. The repackaging of these units requires mental resources, but the gains in handling additional information are extraordinary in the case of some memory mnemonics. While these memory mnemonics require active repackaging, Gestalt principles such as spatial and temporal grouping may spontaneously form information chunks with little overt processing (Koch & Hoffmann, 2000; Koch, Philipp, & Gade, 2006).

The effects of Gestalt principles are well documented in vision, and to a lesser extent, audition, but there is relatively little research examining the role of these principles on somatosensory information. Again, research on control surfaces and haptics (Sanders & McCormick, 1993; Chang & Nesbitt, 2006) are exceptions to this, but there is a dearth of research examining the effects of spatial organizing principles, such as grouping or spatial proximity, on passive vibrotactile displays. Given the cross-modal nature of spatial perception and the visuo-tactile cortical linkages in orientation of attention (Driver & Spence, 1998), it may prove imperative to ascertain the influence of stimulus grouping principles on vibrotactile displays. Such work could improve not only tactile displays, but further the understanding and facilitate the implementation of multisensory displays in a manner that will minimally interfere with concurrent memory demands.

CHAPTER THREE: EXPERIMENTING WITH SPATIALLY UNGROUPED AND GROUPED STIMULI

Method

Purpose

The purpose of this experiment is to determine the effects of concurrent WM (Baddeley & Hitch, 1974; Baddeley, 2001) load on retrieval of multisensory information (sets of either 3 or 6 items) using unimodal cues (visual, auditory, and tactile). The experiment uses a modified Sternberg (1966; 1969) recall task procedure. The recall version of this task was selected over the recognition version of the task (e.g., "Was a probe *present* in the memorized sequence?") due to the ease with which participants could remember which items were present or which few were absent. However, each set of multisensory stimuli in the Sternberg task will be tailored to either minimize or maximize the spatial grouping principles typically found in Gestalt organizational strategies. This study explores the interplay of somatosensory, visual, and auditory information within the established components of WM. The spatial grouping of stimuli will also help to ascertain the representations of multimodal stimuli in memory.

Participants

A power analysis was performed assuming $\alpha = .05$, $1\text{-}\beta = .80$ and using effect sizes based on previous multimodal Sternberg tasks. This analysis suggested a minimum N = 16 to 22. Ultimately 30 participants completed the experiment for both spatially ungrouped and grouped stimuli (total N = 60). Participants were recruited from undergraduate courses from the University of Central Florida and were compensated with extra-credit.

Apparatus

Visual stimuli were presented using a 19" CRT monitor. Auditory stimuli were presented using Sennheiser HD 280 Pro headphones at approximately 60 dB. Tactile stimuli were applied using Engineering Acoustics, Inc. (EAI) model C2X electromechanical vibrotactile actuators, hereafter referred to as a "tactors." Each tactor consists of a metal housing approximately the size of three stacked quarters with a 7mm diameter center plunger (see Figure 1).

Figure 1. C2 tactor.

Activating the tactor displaces the center plunger, moving it against the skin repeatedly to create the vibratory stimulus. Each tactor was affixed to an elasticized belt, creating a ring of eight equidistant tactors worn around the abdomen approximately 1” above the navel. This particular arrangement was shown to produce relatively easy localization of individual tactors (Cholewiak, Collins, & Brill, 2001; Cholewiak, Brill, & Schwab, 2004). The tactile signal waveform (250 Hz sinusoid) was created using a Tektronix® AFG 320 two-channel function generator.

Cross-modal matching procedures (Stevens, 1959) had pilot participants match the auditory amplitude to the tactile display. The brightness of the visual stimulus intensity was similarly matched to the perceived auditory stimulus intensity. A Pentium® 4 PC controlled the presentation timing and response capture for all stimuli using Cedrus®’s experimentation software package SuperLab® 4.0. A numeric keypad modified captured participant responses, as the modifications approximated the spatial layout of the various stimuli.

Stimuli

Visual stimuli consisted of a circle with eight smaller red circles at equidistant points along the cardinal and intermediate cardinal positions (every 45°). The entire visual display subtended a visual angle of approximately 26.4°, and each red circle subtended an angle of 2.6° A red circle changing to green for 500 ms represented a single unit of a visual sequence. Please see Figure 2, Figure 3, and Figure 4 for examples of the Sternberg task visual stimuli.

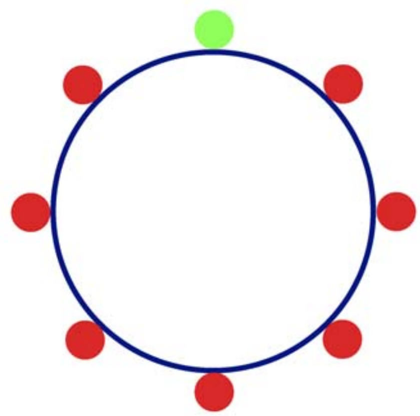

Figure 2. Example of visual stimulus for position 1 (Sternberg task). This corresponds with tactile stimulation near the navel and the auditory label "one."

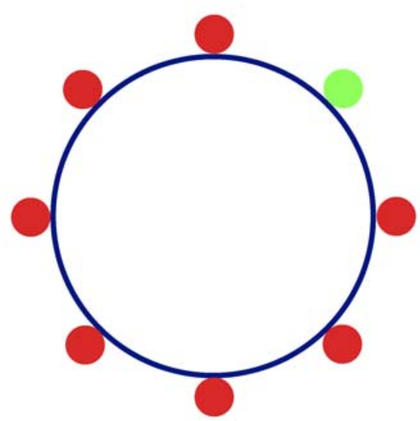

Figure 3. Example of visual stimulus for position 2 (Sternberg task). This corresponds with tactile stimulation to the right of the navel and the auditory label "two."

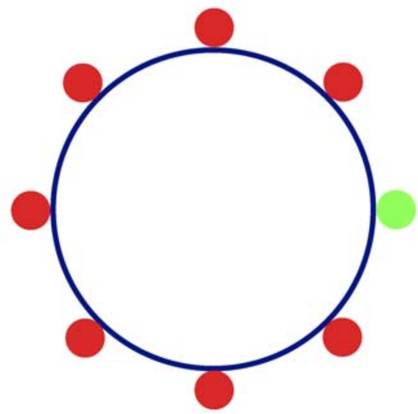

Figure 4. Example of visual stimulus for Sternberg task. This corresponds with tactile stimulation on the extreme right side of the body and the auditory label "three."

Auditory stimuli consisted of a male speaker vocalizing the numbers one through eight. Each verbal number was approximately 500 ms in audible length. Verbal numbers were selected due to the lack of interference found for semantically related, simultaneous presentations of visual and auditory stimuli. Unrelated visual and auditory stimuli (e.g., a picture of a dog and a 1000 Hz tone) paired during encoding hampered accuracy and response latencies for subsequent unisensory probes (Lehmann & Murray, 2005). Tactile stimuli consisted of a 500 ms 250 Hz sinusoidal signal delivered to one of eight vibrotactile actuators (hereafter referred to as tactors).

Each list of three or six items was randomly generated from the eight possible locations, but in the ungrouped condition, careful attention was paid to avoid creating any obvious groupings or numerical arrangements that would impinge on the spatial grouping strategies. Each visual, auditory, and tactile element was checked to ensure that stimuli onsets and durations were equal. In the spatially grouped condition, the stimuli are very similar to those used in the ungrouped condition. However, the items of each list were not randomly generated. The stimuli in each set (for both set sizes) were grouped together into distinct areas, though their order was not purely sequential to prevent the principle of good continuation from confounding the spatial proximity principle. For example, the stimuli in a three-item set may consist of the top point of the circle and the adjoining points on the left and right. These correspond with the spoken numbers '1', '2,' and '8.' The corresponding tactile stimuli were the stimuli around the navel as well as the adjoining left and right tactors. For a six-item sequence, this first set of stimuli would be paired with auditory, tactile, and visual stimuli for positions '4,' '5,' and '6.' In this way, the stimuli of a six-item sequence are grouped into easily identifiable three-item sets. Please Appendix K for illustrations of stimulus sequences.

Procedure

Participants completed the informed consent statement, a demographics questionnaire, a visual span task, auditory span task, and tactile span task. In the visual span task, participants viewed a 4X4 grid pattern (black lines on white background) on a computer screen (see Figure 5). Elements within the grid pattern would sequentially flash black for 1000 ms before returning to normal.

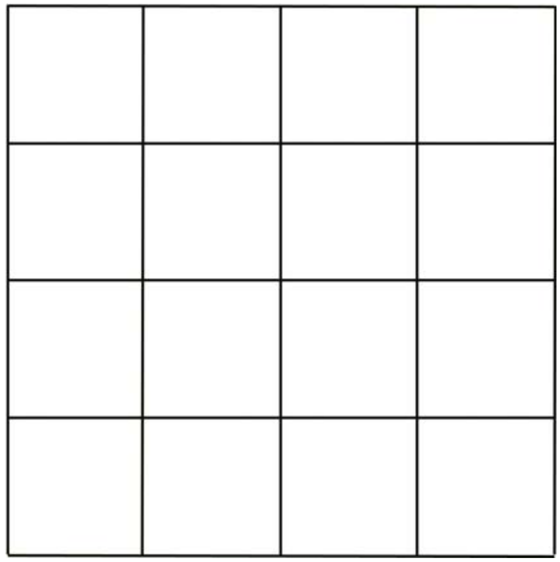

Figure 5. Example of blank grid for visual WM span and loading tasks.

The number of elements that flashed black started at two and continued to increase until the participant could not recall which elements flashed black for a given length. Participants recorded their recall on a sheet with the grid pattern, and were instructed to place mark in each square if it flashed black. Span was reached once the participants failed to recall the sequence items twice with perfect accuracy. A modified procedure was used for determining auditory span. A sequence of verbal letters was read aloud, beginning at a length of two with a speaking rate of approximately one letter every 1.5 s. After hearing each sequence, participants repeated the sequence back to the experimenter. The procedure continued with the sequence increasing in length until the participant failed to provide all letters in the sequence length, irrespective of order. As with the visual span test, a failure at one length prompted another attempt with a sequence of equal length. Two failures of a particular length indicated that span had been reached. The experimenter assessed tactile span by modifying this increasing length procedure for tactile stimuli (Mahrer & Miles, 2002). The tactile stimuli consisted of the experimenter using a pen to tap a sequence on the upturned fingertips of the participant. Each lasted for approximately 1 s and the participant's eyes were closed during the stimulus presentations. Participants recalled the sequence applied by moving each finger that was tapped. The experimenter recorded accuracy irrespective of order.

Participants also completed the Gestalt Completion Test (Ekstrom, French, Harman, & Derman, 1976), the Paper Folding Test (Ekstrom et al., 1976), and the Associative Memory-Picture Number Test (Ekstrom et al., 1976). As Gestalt spatial organizing principles are central to this work, individual differences in spatial relations, pattern detection (and grouping), and memory encoding ability were captured for further analysis. These tests were included to evaluate participants' Gestalt completion, spatial, associative memory abilities across the spatially ungrouped and grouped stimuli conditions. They were used to ensure that any differences detected between the two groups would be due to the stimulus manipulation and would not reflect an inherent cognitive performance difference.

Each participant was then measured around the abdomen in order to custom fit the tactile display. This measurement was divided by eight to ensure the tactors are spaced equidistantly around the abdomen. While the experimenter prepared the tactile display, the participant selected a white, cotton T-shirt in order to standardize the material in between the tactors and the skin. Once an appropriate shirt size was selected, the participant changed in a private room.

After changing, the experimenter fitted the participant with the tactile display and seated him/her in front of the monitor and response pad. The participant donned the headphones and the experimenter began the computerized instructions about how to perform the recall task. The participant was allowed to ask questions at any time during this instructional phase. Each participant was familiarized with all of the available stimuli across all three modalities, and how these stimuli corresponded with one another. Specifically, the visual-tactile spatial relationship and the auditory number sequence for each spatial position was emphasized through simultaneous presentation of each memory item (e.g., spatial position and corresponding number). The automated instructions then presented example sequences for the recall task using the visual, auditory and tactile stimuli, and the participant had to respond according to the recall task directions. To perform the task correctly, participants memorized the set of stimuli for that set of trials. To ensure transfer to LTM, participants were presented with each set four times. The participant was then asked to perform basic mathematical operations for 60 s and then recall the set presented. There was then another 60 s of basic mathematical operations and another recall of the full sequence. Once the participant could recall the memorized set twice with no errors, the set was considered to be sufficiently memorized. The purpose of the arithmetical filler task was to occupy WM and remove the recency effect during subsequent recall.

In this modified Sternberg recall task, the participant memorized a set of multisensory stimuli and was then presented with a unisensory probe stimulus. For example, the participant memorized a sequence of three corresponding and simultaneous visual, auditory, and tactile stimuli. The probe stimulus was only a single visual, auditory, or tactile stimulus from this set. To perform each trial correctly, participants responded with the stimulus that followed the probe stimulus from the memorized sequence set. To clarify, if the memorized set is “1, 8, 4, 7, 3” (simultaneous visual, auditory, and tactile) and the probe stimulus is “4,” then the correct response would be “7.” This is because “7” follows “4” in the memorized sequence. If the probe stimulus was the last position in the sequence, then the participant was instructed to respond on the response pad with the first position in the sequence.

After the instructional phase, each participant was instructed to respond as quickly as possible, but they should not sacrifice accuracy for speed. Responses consisted of depressing the corresponding key on the respond pad.

Each participant memorized a three-item list and a six-item list for each of the three WM loading task conditions (visual, auditory, and tactile). In each WM loading task condition, participants performed the Sternberg task while either maintaining the WM loading information in memory or after completing the WM task. Each participant completed 12 trials for each modality under each secondary task condition. The order of the unisensory probe blocks and the individual sequence items was randomized.

The WM loading tasks were intended to occupy elements of WM. To occupy the VSSP, participants viewed a grid (similar to the WM visual span task) on a nearby monitor. Five elements of a 4 X 4 white grid randomly and sequentially filled with black squares (1 s duration for each square with 100 ms in between) presented to the participants before beginning each block of trials (adapted from Logie et al., 1990; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Logie & Pearson, 1997). Participants were instructed to maintain this random visual sequence in memory, and to recall it upon completing a set of trials using the modified Sternberg task. The randomization was screened for any block patterns that formed obvious shapes such as squares, rectangles, or letters. The block of Sternberg task trials (either visual, auditory, or tactile unisensory memory probes) then began and after completing the block, the participant filled in the squares on a provided piece of paper with the initial white grid. To occupy the PL, five letters, spoken at a rate of one letter per second, were presented to the participant with the same instructions as the VSSP task (adapted from Cocchini, Logie, Sala, MacPherson, & Baddeley, 2002). Upon completing a block of trials in the modified Sternberg task, the participant must then repeat the list of letters. The letter strings were randomly generated, however only sequences that did not include any unintentionally formed words, acronyms, or rhyming letters (to avoid obvious memory encoding strategies or acoustic confusions) were used. To create a tactile loading, the experimenter tapped the cap end of a pen onto five randomly ordered fingertips (participant held both palms up). The tapping rate was approximately one tap per 1.5 sec, with each tap lasting approximately 1 s. These orders were screened to remove any that followed a sequential ordering (3 or more in a row) or easily identifiable pattern.

To reiterate the procedure, the experimenter initially assigned the participant randomly to one of the counterbalanced orders of secondary task loading (VSSP, PL, or tactile), sequence length presentation (3-item first or 6-item first), and baseline presentation (interleaved Sternberg task with secondary task memorization, or separated tasks) for either the spatially grouped condition or spatially ungrouped condition. This was done to help properly distribute any potential effects of learning or fatigue.

The participant memorized a multisensory stimulus set (either 3 or 6 items in length). After memorization, the participant was randomly assigned to a particular unisensory probe order (a variant of “visual, auditory, then tactile”). Depending upon the order assignment condition, the experimenter would then present the secondary task stimuli. If the tasks were interleaved, then the participant would have to maintain the secondary task stimuli in memory while performing the Sternberg task. After completing the Sternberg task, the participant would then have to recall the secondary loading stimuli. The participant was then presented with another secondary loading, performed another block of trials with the next unisensory probe modality, and subsequently recalled the secondary loading stimuli. This procedure was repeated for the last unisensory probe modality. Next, the participant completed another full set. However, the participant could recall the secondary stimuli immediately after their presentation and not have to maintain them in memory while completing the Sternberg task trials. This helped to establish a baseline for Sternberg task performance and secondary stimuli recall for the interleaved task portion.

Once the participant completed the interleaved and baselines, he/she would learn a new Sternberg sequence and repeat the procedure for interleaved/baseline tasks for each remaining combination of sequence lengths (3- and 6-items) and WM loading task types (VSSP, PL, and tactile finger-tapping). A sample task sequence would be:

- Learn multimodal sequence
    - Baseline
        - Complete visual WM loading task (baseline)
        - Perform Sternberg Task (visual) with learned sequence (baseline)
        - Complete visual WM loading task (baseline)
        - Perform Sternberg Task (auditory) with learned sequence (baseline)
        - Complete visual WM loading task (baseline)
        - Perform Sternberg Task (tactile) with learned sequence (baseline)
        - Complete visual WM loading task (baseline)
    - Interlaced tasks
        - Present visual WM loading task
            - Perform Sternberg task (visual) with learned sequence
        - Recall visual WM loading task

    - Present visual WM loading task
        - Perform Sternberg task (auditory) with learned sequence
    - Recall visual WM loading task
    - Present visual WM loading task
        - Perform Sternberg task (tactile) with learned sequence
    - Recall visual WM loading task
- Repeat with new Sternberg task sequence for all set sizes and WM loading task modalities

Experimental Design

The structure for this experiment is a 2 x 3 x 3 x 2 mixed factorial design. Three of the variables are within-subjects factors. he first factor in design is set size (3 and 6 items), and the second is probe modality for cued retrieval (visual, auditory, tactile). The third factor is WM secondary loading with three levels: visuo-spatial sketchpad (VSSP) loading, phonological loop (PL) loading, and tactile loading. The final factor is the between subjects factor of spatially ungrouped and spatially grouped stimuli.

Hypotheses

The following hypotheses will be tested:

H1:

Response times will increase for the increased set size irrespective of unisensory probe modality.

H2:

Response times will be longer for concurrent WM loadings across set sizes as opposed to no concurrent WM loading.

H3:

Response times will be longer across set sizes when unisensory-probe and concurrent WM loading task modalities match.

H4:

Response times will be longer for auditory probes in the small set size. Tactile and visual probe response times will be indistinguishable at the smaller set size. No probe modality differences will appear in the large set size.

H5:

Response times will increase for the increased set size across probe modalities. However, response times will be reduced for the stimuli grouped according to spatial proximity more than the ungrouped stimuli, but only for visual and tactile unisensory probes.

H6:

WM load accuracy will be reduced in instances of matched WM loading modalities and unisensory probe modalities.

H7:

Spatially grouping the Sternberg stimuli will reduce encoding difficulty for the larger set size versus ungrouped stimuli.

Dependent Measures

Response Time

Response time for each trial begins with the onset of the retrieval probe and ends with the selection of the next item from the memorized set. The latency of the response should prove highly effective in demonstrating any memory interference effects. RT differences for correct responses form the foundation of the majority of Sternberg's experiments (1966; 1969). The multimodal modification of the recall task will use response latency sensitivity to partially ascertain experimental effects.

Accuracy

Accuracy of response is the percent correct for a set of WM loading task stimuli. Response accuracy is a sensitive measure in many experimental paradigms, with considerable memory research (specifically, retrieval of memory) showing response accuracy to be robust in recall tasks despite concurrent task loads. Baddeley, Lewis, Eldrigde, & Thomson (1984) conducted a plethora of memory experiments and generally found that retrieval accuracy was not significantly impinged by concurrent tasks. However, etrieval latency was affected. This effect is also demonstrated in other research as well (for a review, see Pashler & Johnston, 1998). Based on these previous findings, this experiment will focus on response latencies in the Sternberg task. However, accuracy will serve as the measure in the WM loading tasks.

Encoding Difficulty

Encoding difficulty is defined as the number of presentations required for the participant to encode a set of multisensory stimuli. Once the participant is able to recall the set perfectly despite intervening counting tasks, the set will be considered to be sufficiently encoded into memory. Based on the previous findings in memory research (Baddeley et al, 1984; Pashler & Johnston, 1998), encoding difficulty may serve as another useful measure when comparing grouped versus ungrouped stimuli.

CHAPTER FOUR: RESULTS

Pre-test Measures

The pre-tests administered to each participant serve a useful check on the spatial, associate memory, and Gestalt completion abilities for each spatial grouping condition. Working memory spans were also assessed for visual, auditory and tactile stimuli. Similar scores across each group help to ensure that any observed findings are the result of the experimental manipulations.

Paper Folding

Paper folding tests were scored according to test instructions for each participant. The mean scores for participants in the spatially ungrouped condition and spatially grouped condition were 10.79 (*SD* = 4.78) and 10.75 (*SD* = 4.03), respectively. A two-sample, two-tailed *t*-test revealed no significant difference between the mean scores for the two conditions, $t(58) = -.03$, $p = .97$.

Gestalt Completion

Gestalt Completion tests were scored according to test instructions for each participant. The mean scores for participants in the spatially ungrouped condition and spatially grouped condition were 13.47 (*SD* = 3.33) and 12.80 (*SD* = 2.63), respectively. Again, a two-sample, two-tailed *t*-test revealed no significant difference between the two conditions, $t(58) = -.86$, $p = .39$.

Associative Memory

Associative memory tests were scored according to test instructions for each participant. The mean scores for participants in the spatially ungrouped condition and spatially grouped condition were 14.67 (*SD* = 4.81) and 14.33 (*SD* = 4.17), respectively. As with the other tests, the *t*-test revealed no significant difference between the mean scores for the two conditions, $t(58) = .29$, $p = .78$.

Working Memory Spans

The mean visual, auditory, and tactile working memory spans were visual = 5.96 (*SD* = 1.75), auditory = 6.90 (*SD* = 1.15), and tactile = 4.73 (*SD* = 1.05). A one-way analysis of variance (ANOVA) yielded a significant result, $F(2,57) = 79.37$, $p < .001$, partial $\eta^2 = .736$. Subsequent pair-wise comparisons showed that each working memory span significantly differed from the other two ($p < .005$). The means for each visual, auditory, and tactile working memory span were also compared for each set of participants in the spatially ungrouped and spatially grouped conditions. These specific comparisons were of interest to ensure that the participants in the grouped and ungrouped conditions did not significantly differ along the WM span dimensions. For the spatially ungrouped and grouped conditions, the mean visual spans were 6.08 (*SD* = 1.92) and 5.83 (*SD* = 1.74), respectively. A *t*-test revealed no significant difference between the two, with $t(58) = -.54$, $p = .59$. For the spatially ungrouped and grouped conditions, the mean auditory spans were 6.86 (*SD* = 1.18) and 6.93 (*SD* = 1.14), respectively. A *t*-test revealed no significant difference between the two, with $t(58) = .24$, $p = .81$. For the spatially ungrouped and grouped conditions, the mean tactile spans were 4.78 (*SD* = 1.10) and 4.70 (*SD* =

1.08), respectively. A *t*-test revealed no significant difference between the two, with $t(58) = -.31$, $p = .75$.

Response Times for Sternberg Task

The mean response time was computed for each block of trials for a given unisensory stimulus probe (either visual, auditory, tactile). Only means for correct responses were counted. These were also screened for any that were beyond three standard deviations from the mean to account for outliers. No more than 2 trials were removed from any given block of trials. The response time data was also screened for normality, with skewness and kurtosis information shown in Appendix B and Appendix C. To account for any deviations from normality, a base-10 logarithmic transformation was performed and it brought the majority of scores within the bounds of normality (Tabachnick & Fidell, 2007). However, analyses with the transformed data did not alter the ultimate findings, so the data reported here are based on the untransformed data to reduce any difficulties in interpretation and reporting.

A repeated-measures analysis of variance (ANOVA) on the baseline task data (no WM loading tasks) was performed with the Sternberg task modality (visual, auditory, tactile) and set size (3-items, 6-items) as the independent variables. This yielded a significant main effect for Sternberg task modality, $F(2, 57) = 58.638$, $p < .001$, partial $\eta^2 = .673$, as well as a significant interaction with set size, $F(2, 57) = 6.574$, $p < .005$, partial $\eta^2 = .187$ (see Table 1 and Figure 6). Subsequent pair-wise comparisons (using LSD because hypotheses did specify predictions) show that response times differed significantly for all modalities in the 3-item level. Visual response times were fastest, followed by tactile and then auditory response times. However, for 6-item sets, visual was significantly faster than both auditory and tactile. The latter two did not differ significantly in the 6-item sets.

Table 1. *Sternberg Task Set Size and Sternberg Task Modality.*

Set Size	Sternberg Task Modality	*M*	*SD*	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
3-item	Visual	1098.424	378.787	1000.537	1196.310
	Auditory	1367.931	323.513	1284.328	1451.534
	Tactile	1266.339	435.359	1153.833	1378.844
6-item	Visual	1796.771	460.844	1677.680	1915.863
	Auditory	2094.973	455.154	1977.352	2212.594
	Tactile	2115.739	524.909	1980.091	2251.386

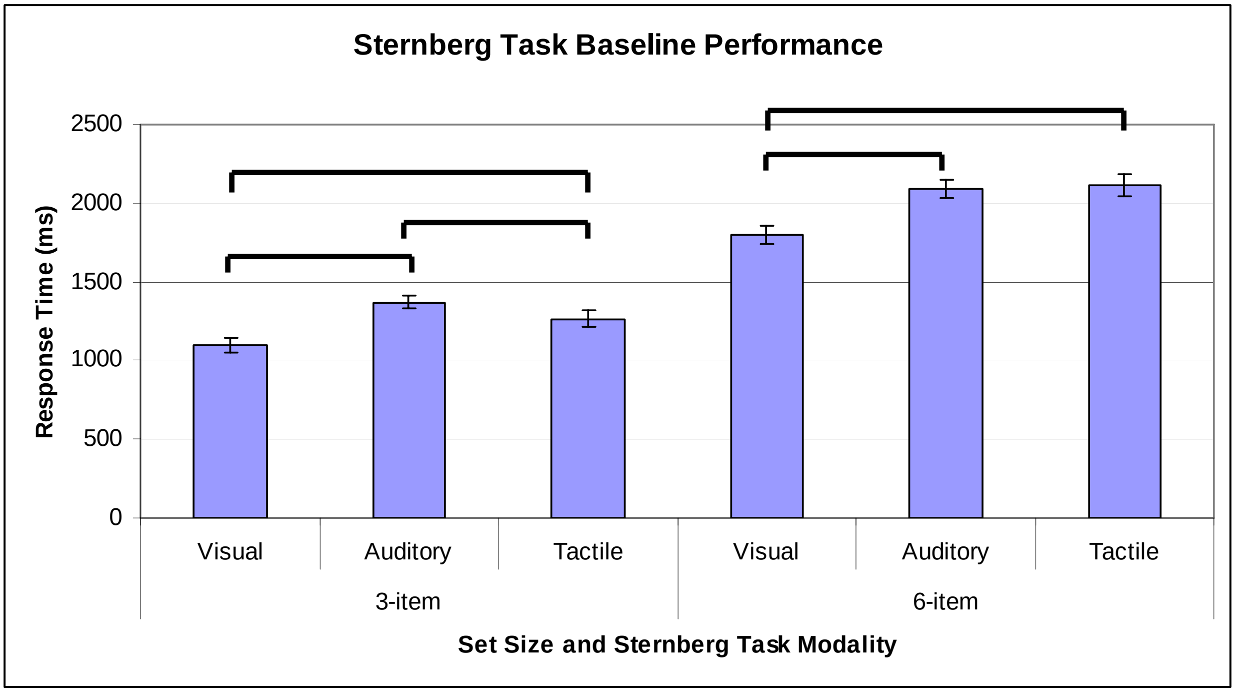

Figure 6. Effects of Sternberg task set size and modality on baseline response times. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was also a three-way interaction of Sternberg task modality, set size, and spatial grouping on the baseline response time data, $F(2, 57) = 12.698$, $p < .001$, partial $\eta^2 = .308$ (see Table 2, Figure 7, and Figure 8). To inspect this interaction, additional analyses based on the aforementioned hypotheses broke this interaction down along the set size variable. This was selected because based on previous literature and current data, it is reasonable to assume that increased set sizes would yield increased response times. Therefore, the data of interest may reside in the modality by grouping analyses at each set size. Pair-wise comparisons based on the hypotheses mentioned earlier (specifically, hypotheses 1, 4, and 5) showed that spatial grouping actually increased response times for 3-item tactile sets, but had no impact upon the 3-item visual and auditory sets. For 6-item sets, spatial grouping significantly shortened response times to visual and tactile stimuli, and had no effect on auditory stimuli.

Table 2. *Sternberg task factors (spatial grouping, set size, and modality) on response time.*

Spatial Grouping	Set Size	Sternberg Task Modality	*M*	*SD*	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Grouped	3-item	Visual	1178.336	378.7874	1039.904	1316.769
		Auditory	1426.238	323.5134	1308.006	1544.469
		Tactile	1379.937	435.3587	1220.83	1539.044
	6-item	Visual	1564.455	460.8442	1396.034	1732.876
		Auditory	2055.936	455.1542	1889.595	2222.278
		Tactile	1909.782	524.909	1717.948	2101.616
Ungrouped	3-item	Visual	1018.511	378.7874	880.0791	1156.944
		Auditory	1309.625	323.5134	1191.393	1427.856
		Tactile	1152.74	435.3587	993.6332	1311.847
	6-item	Visual	2029.088	460.8442	1860.667	2197.509
		Auditory	2134.01	455.1542	1967.668	2300.352
		Tactile	2321.695	524.909	2129.861	2513.529

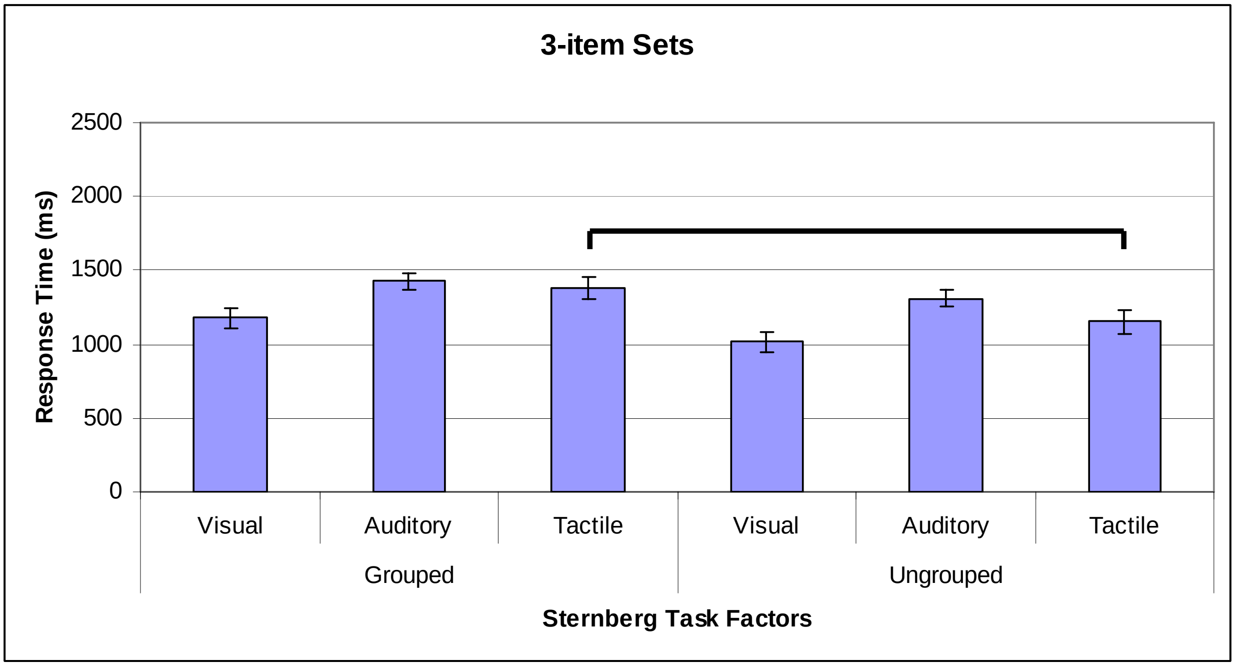

Figure 7. Effects of Sternberg Task Factors on 3-item sets. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

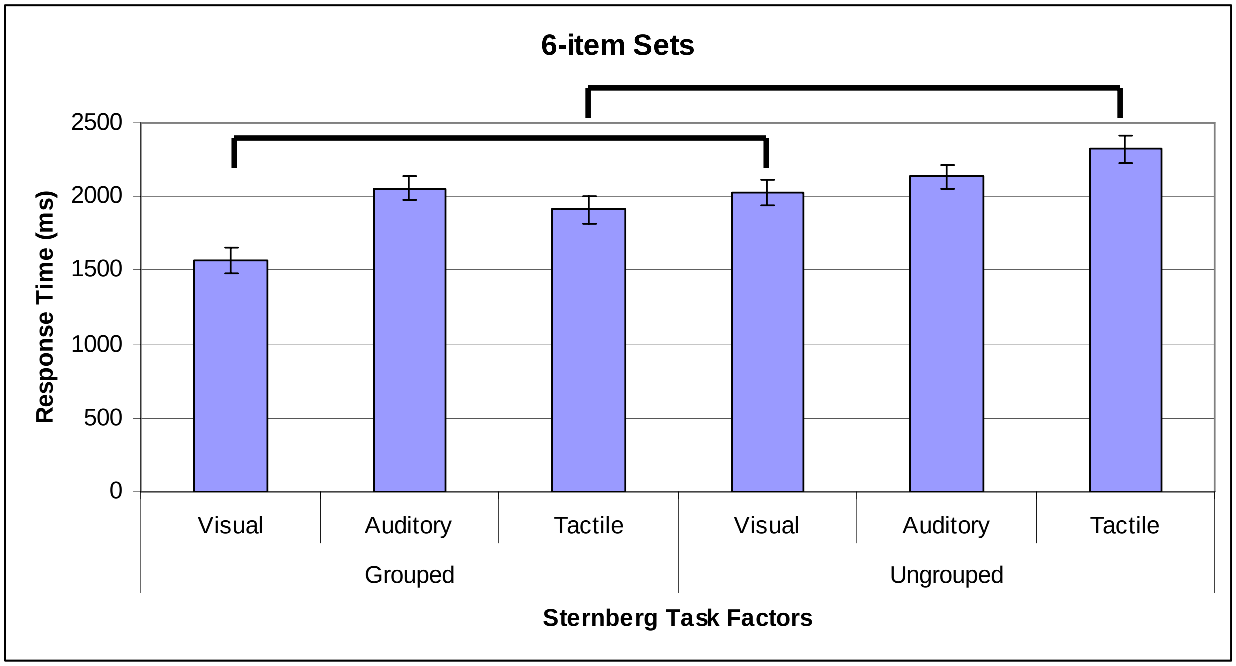

Figure 8. Effects of Sternberg Task Factors on 6-item sets. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

To further determine the effects of WM loading tasks, set sizes, and spatial grouping on each Sternberg task modality, responses times for each Sternberg task modality were subjected to a repeated-measures ANOVA. The within-subjects factors were WM loading task condition (no loading, visual, auditory, or tactile) and Sternberg task set size. The betweens-subjects factor was spatial grouping of stimuli. Each of the next three sections represents this analysis performed on the response times for each of the Sternberg task modalities (visual, auditory, and tactile).

Visual Sternberg Task Response Times

There was a significant main effect of set size on the visual Sternberg task, $F(1, 58) = 183.724$, $p < .001$, partial $\eta^2 = .760$. The mean response time was 1165.299 ms ($SD = 333.216$) for 3-items sets and 1884.264 ($SD = 500.963$) for 6-items sets (see Figure 9 for an illustration). This indicates that participants were significantly faster in performing the visual Sternberg task with the smaller set sizes.

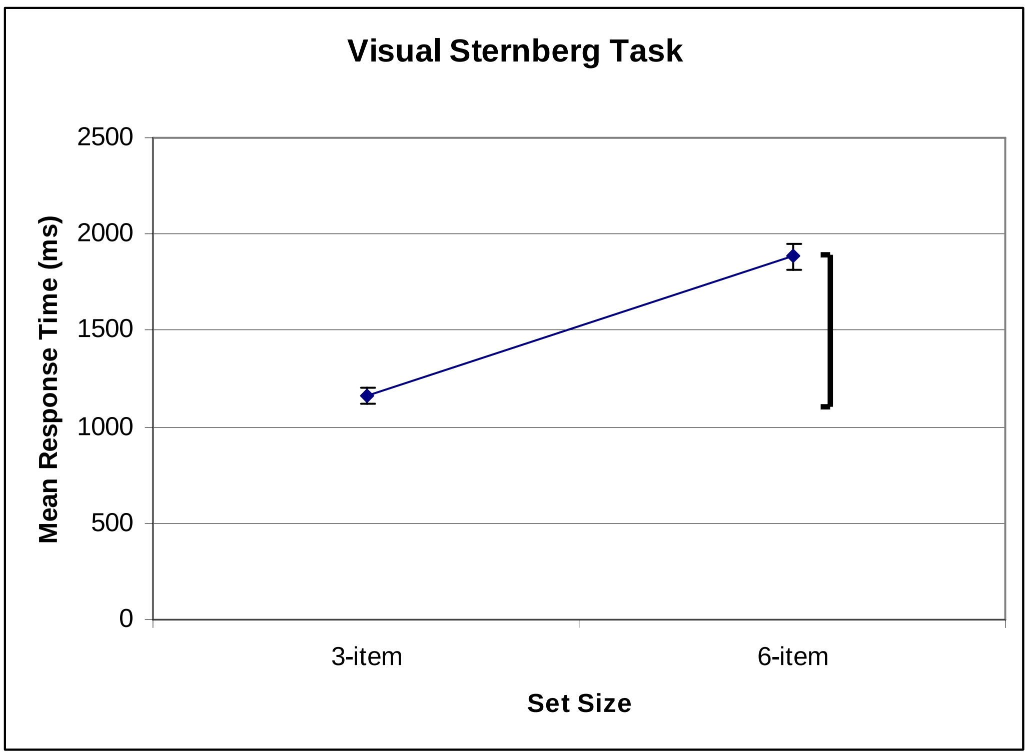

Figure 9. Effects of set size on response times for visual Sternberg task stimuli. Error bars represent standard error.

There was no main effect of spatial grouping, $F(1, 58) = 1.966$, $p = .166$, partial $\eta^2 = .033$. However, there was an interaction between Sternberg task set size and spatial grouping, $F(1, 58) = 33.464$, $p < .001$, partial $\eta^2 = .366$ (please see Table 3 and Figure 10). Subsequent pair-wise comparisons were conducted with a Bonferroni correction to account for type-I error inflation. This was used because there was no specific hypothesis regarding this combination of effects while performing the concurrent WM tasks. The pair-wise comparisons show that grouping stimuli tended to slow response times to stimuli in the 3-items sets, though this finding was just above the threshold for significance ($p = .05$). However, for 6-items sets, grouping stimuli improved response times over ungrouped stimuli.

Table 3. *Visual response time data by spatial grouping and set size.*

				95% Confidence Interval	
Spatial Grouping	**Set Size**	***M***	***SD***	**Lower Bound**	**Upper Bound**
3-item	Grouped	1251.278	333.218	1129.499	1373.056
	Ungrouped	1079.321	500.962	1480.319	1846.484
6-item	Grouped	1663.401	333.218	957.543	1201.099
	Ungrouped	2105.127	500.962	1922.044	2288.210

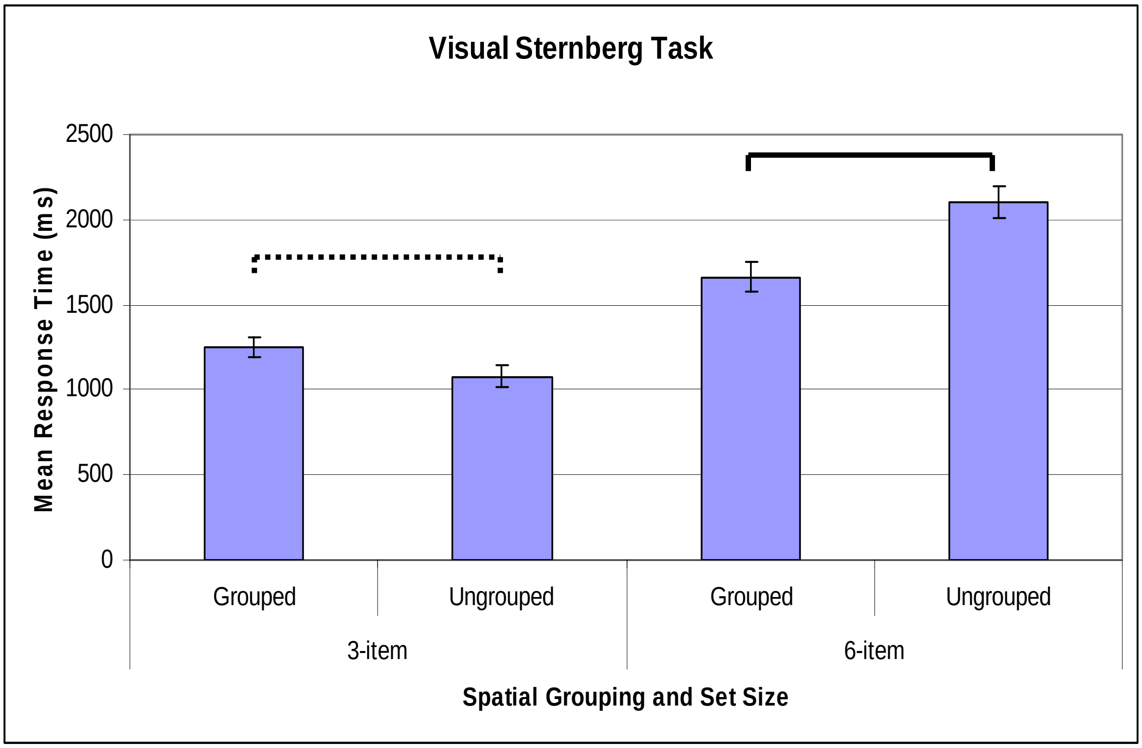

Figure 10. Visual response time data by spatial grouping and set size. Error bars represent standard error. Solid linking bar represents significant difference ($p < .05$); Dashed linking bar represents a trend that did not reach significance.

There was a significant main effect of WM loading task condition on the visual Sternberg task, $F(3, 174) = 2.708$, $p < .05$, partial $\eta^2 = .045$. The mean response times for the visual-alone condition, as well as its pairings with the visual, auditory, and tactile WM loading tasks can be found in Table 4. Subsequent pair-wise comparisons (LSD) were examined to determine locations of the differences. In comparing visual WM loading against the baseline, there was no significant difference. However, response times did significantly increase from baseline while performing a concurrent auditory WM loading task. There was a similar increase from baseline levels while performing the tactile WM loading task (please see Figure 11). There was no significant interaction between WM loading task condition and set size, $F(1, 174) = 2.168$, $p = .094$, partial $\eta^2 = .036$ (see Figure 12).

Table 4. *Effects of WM Loading Task Type on Visual Sternberg Task.*

WM loading task type	***M***	***SD***	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
None	1447.598	362.213	1353.994	1541.201
Visual	1539.120	440.223	1425.357	1652.883
Auditory	1546.926	447.974	1431.160	1662.691
Tactile	1565.483	462.213	1446.038	1684.929

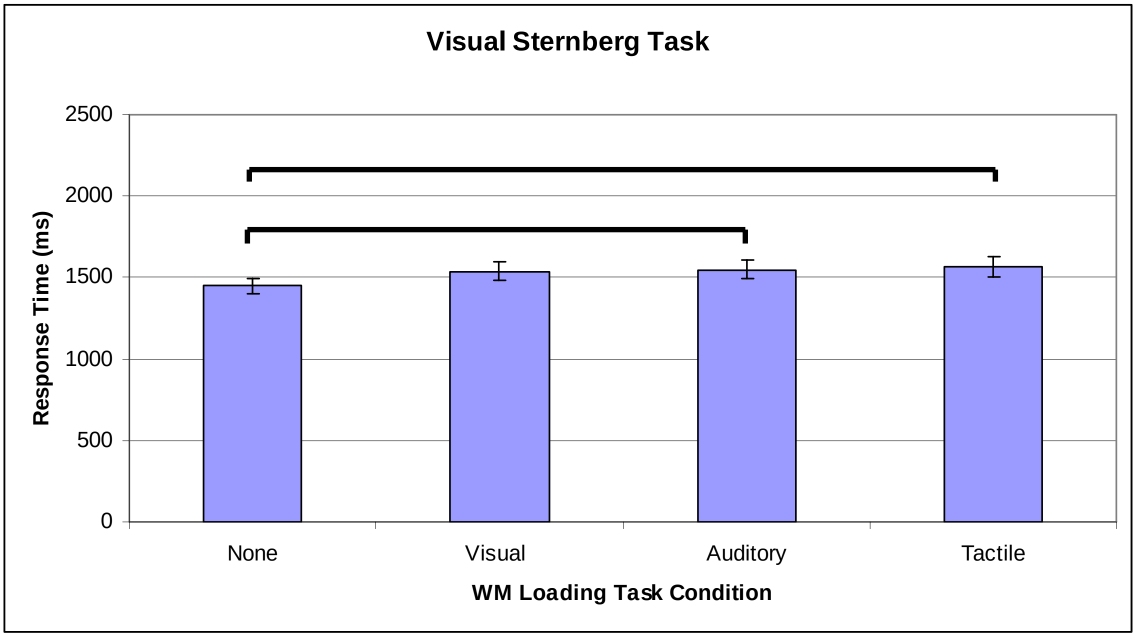

Figure 11. Effects of WM loading task condition on visual Sternberg task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

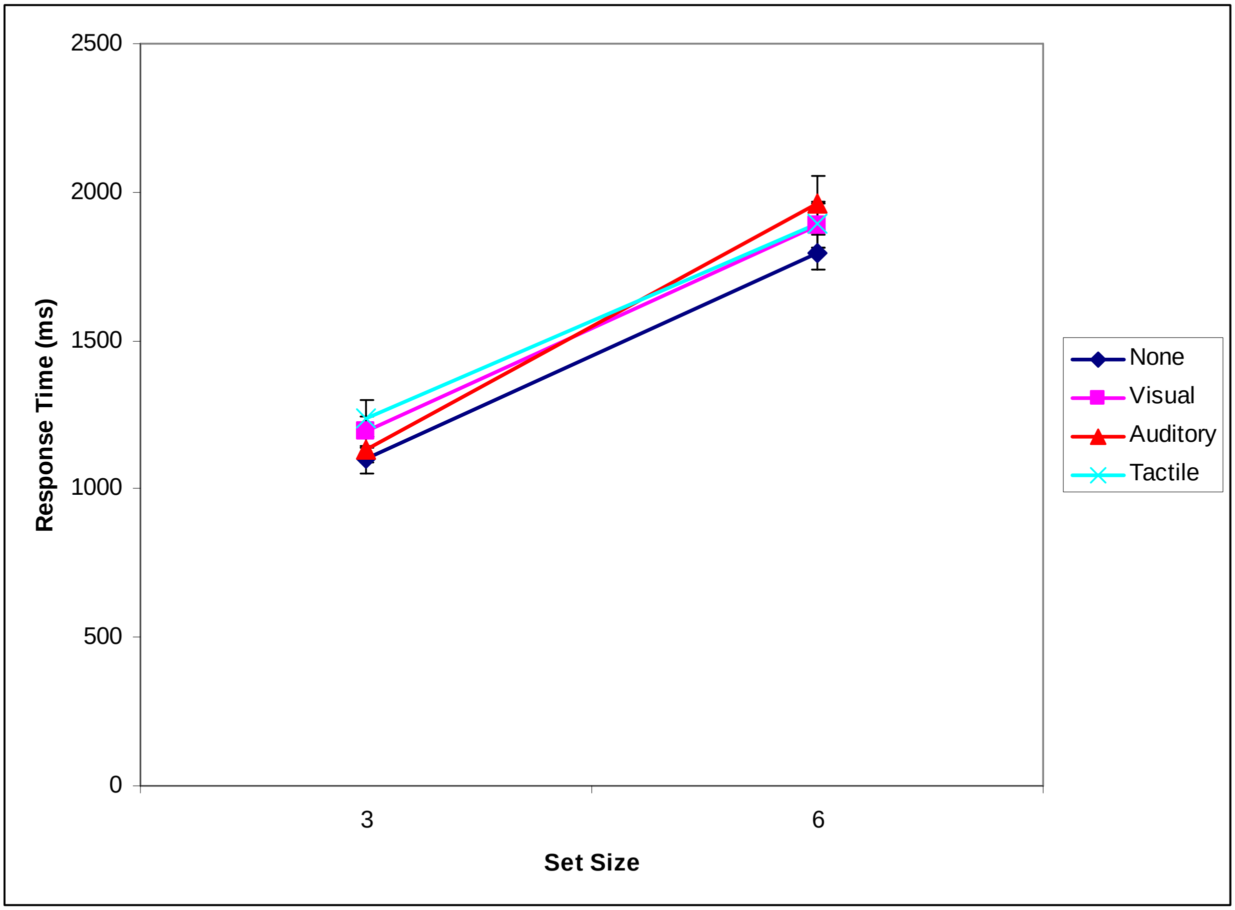

Figure 12. Effects of WM loading task condition on visual Sternberg task by set size.

Auditory Sternberg Task Response Times

There was a significant main effect of set size on the auditory Sternberg task, $F(1, 58) = 304.237$, $p < .001$, partial $\eta^2 = .840$. The mean response time was 1483.403 ms ($SD = 331.69$) for

3-items sets and 2246.011 (*SD* = 492.543) for 6-items sets (see Figure 13 for an illustration). This indicates that participants were significantly faster in performing the visual Sternberg task with the smaller set sizes.

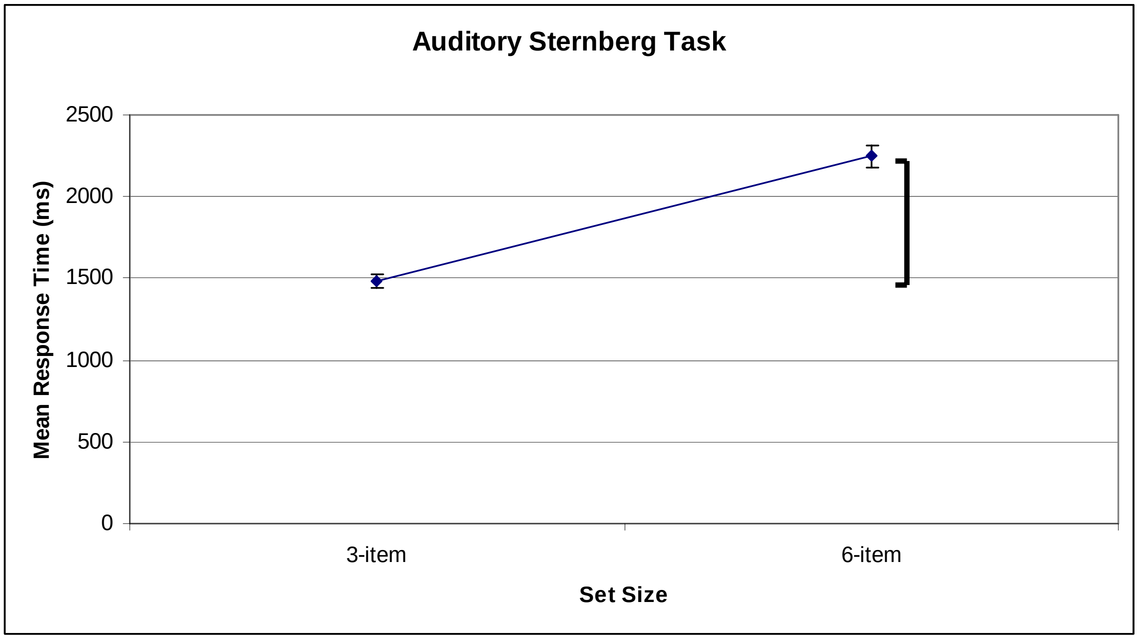

Figure 13. Effects of set size on response times for auditory Sternberg task stimuli. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was no main effect of spatial grouping, $F(1, 58) = .021$, $p = .885$, partial $\eta^2 = .000$. However, there was an interaction between Sternberg task set size and spatial grouping, $F(1, 58) = 7.448$, $p < .01$, partial $\eta^2 = .114$ (please see Table 5 and Figure 14). However, subsequent pair-wise comparisons with a Bonferroni correction to account for type-I error inflation did not reveal a significant effect of grouping at either set size.

Table 5. *Effects of set size and spatial grouping on auditory Sternberg task.*

Spatial Grouping	Set Size	*M*	*SD*	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
3-item	Grouped	1550.299	331.691	1429.078	1671.519
	Ungrouped	1416.508	331.691	1295.287	1537.728
6-item	Grouped	2193.587	492.545	2013.581	2373.593
	Ungrouped	2298.435	492.545	2118.429	2478.442

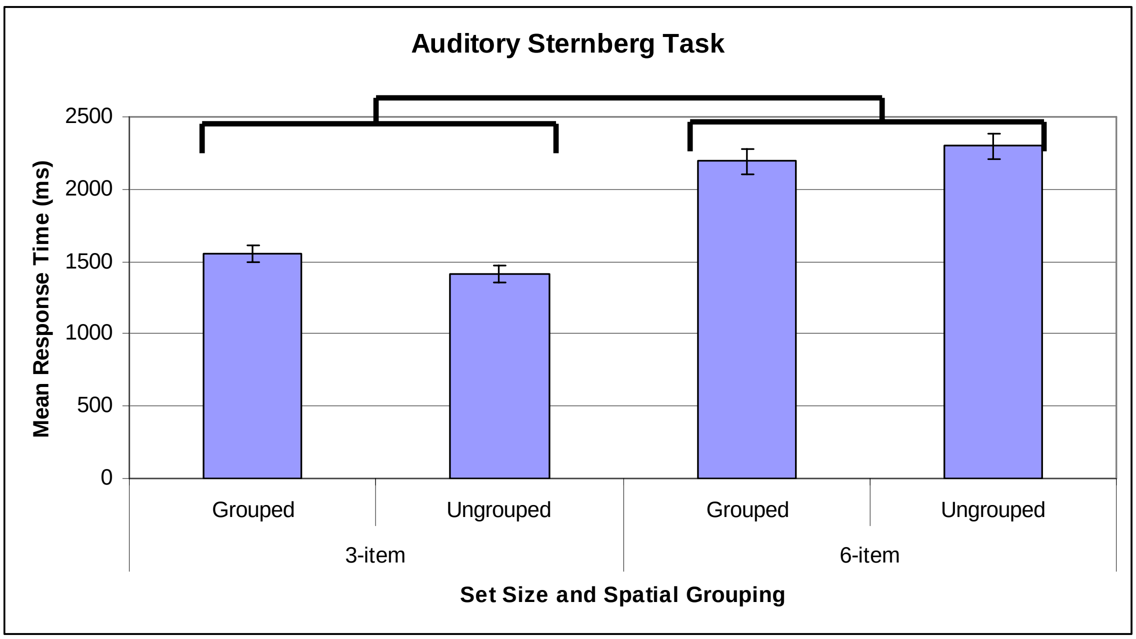

Figure 14. Effects of set size and spatial grouping on auditory Sternberg task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was a significant main effect of WM loading task condition on the auditory Sternberg task, $F(3, 174) = 7.733$, $p < .001$, partial $\eta^2 = .118$. The mean response times for the auditory-alone condition, as well as its pairings with the visual, auditory, and tactile WM loading tasks can be found in Table 6 (also see Figure 15). Subsequent pair-wise comparisons (LSD) were used to determine the nature of the differences. In comparing visual WM loading against the baseline, there was no significant difference. However, response times did significantly increase from baseline while performing a concurrent auditory WM loading task. There was a similar increase in baseline while performing the tactile WM loading task. There was also a significant increase in response time between concurrent performance with the visual WM loading task and the auditory WM loading task. A similar increase was found between concurrent visual and concurrent tactile WM loading task performance. There was no significant interaction between WM loading task condition and set size, $F(1, 174) = 1.619$, $p = .187$, partial $\eta^2 = .027$. Please also see Figure 16.

Table 6. *Effects of WM loading task condition on auditory Sternberg task.*

WM loading task type	***M***	***SD***	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
None	1731.452	349.380	1641.165	1821.739
Visual	1828.163	455.859	1710.359	1945.966
Auditory	1965.701	545.553	1824.719	2106.683
Tactile	1933.513	476.490	1810.378	2056.648

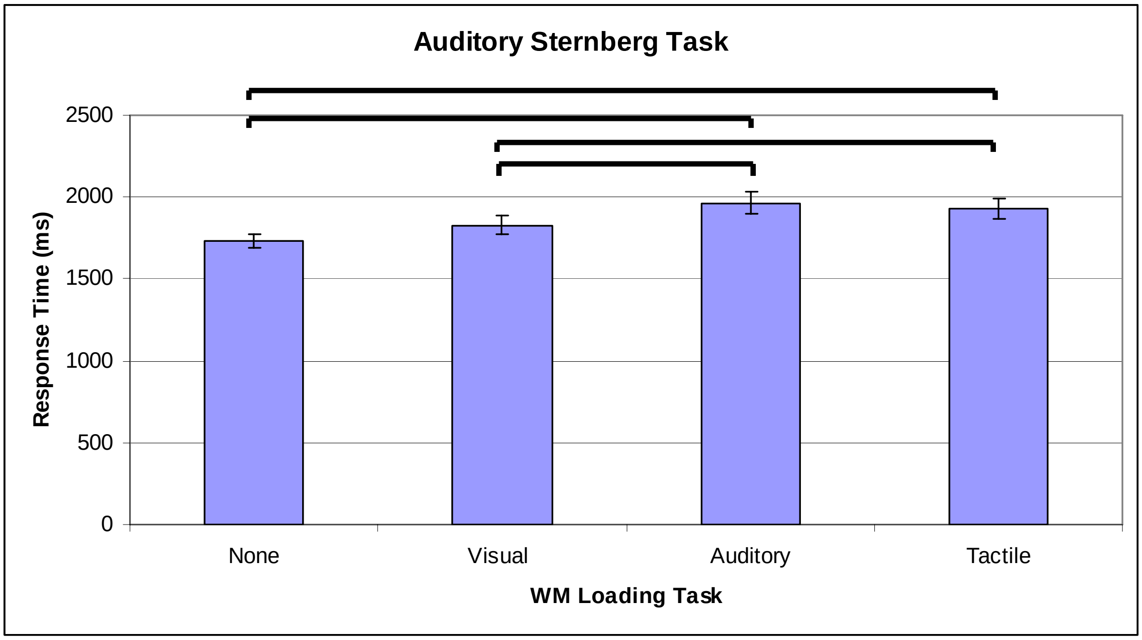

Figure 15. Effects of set size and spatial grouping on auditory Sternberg task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

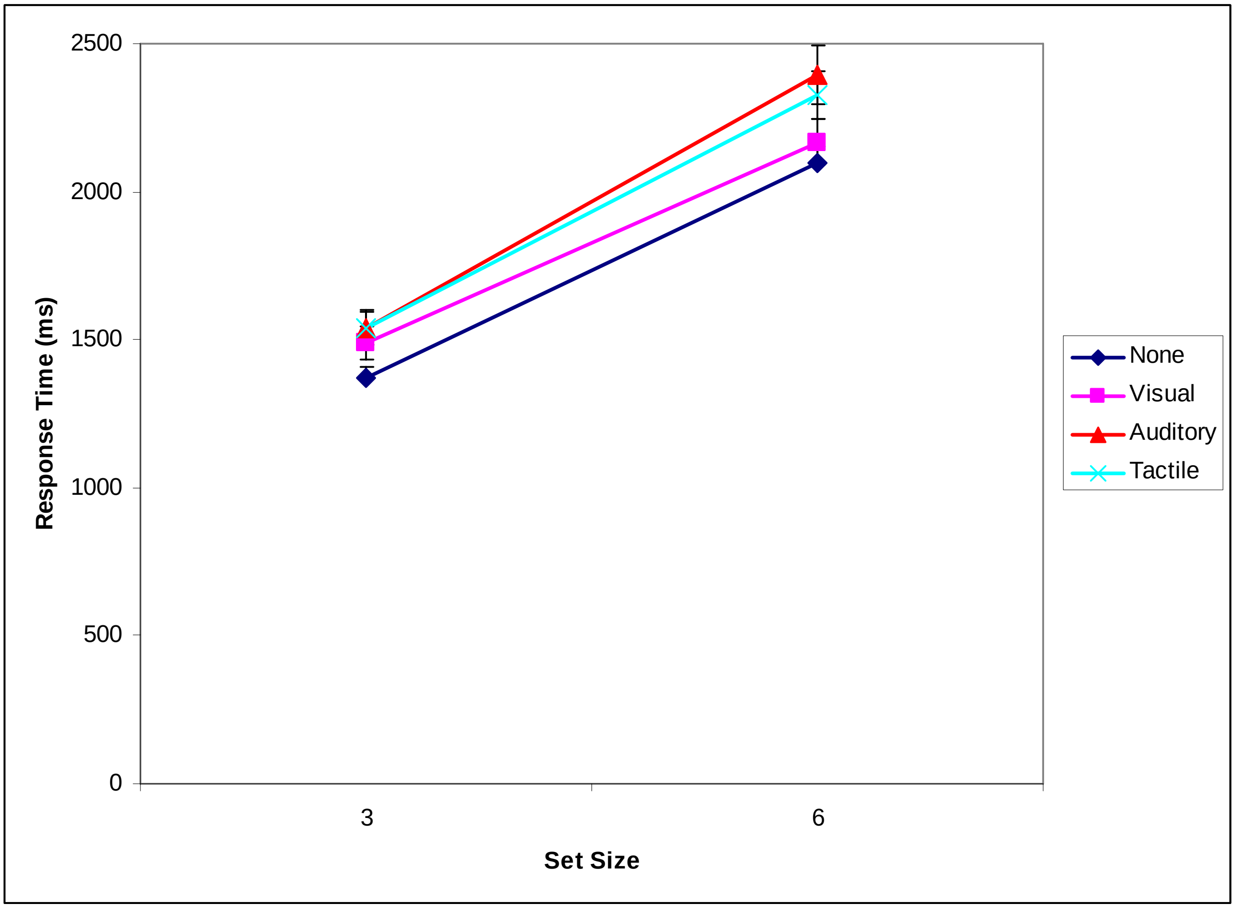

Figure 16. Effects of WM loading task condition auditory Sternberg task by set size.

Tactile Sternberg Task Response Times

There was a significant main effect of set size on the tactile Sternberg task, $F(1, 58) = 314.060$, $p < .001$, partial $\eta^2 = .844$. The mean response time was 1320.381 ms ($SD = 363.077$)

for 3-items sets and 2251.043 (*SD* = 542.249) for 6-items sets (see Figure 17 for an illustration). This indicates that participants were significantly faster in performing the visual Sternberg task with the smaller set sizes.

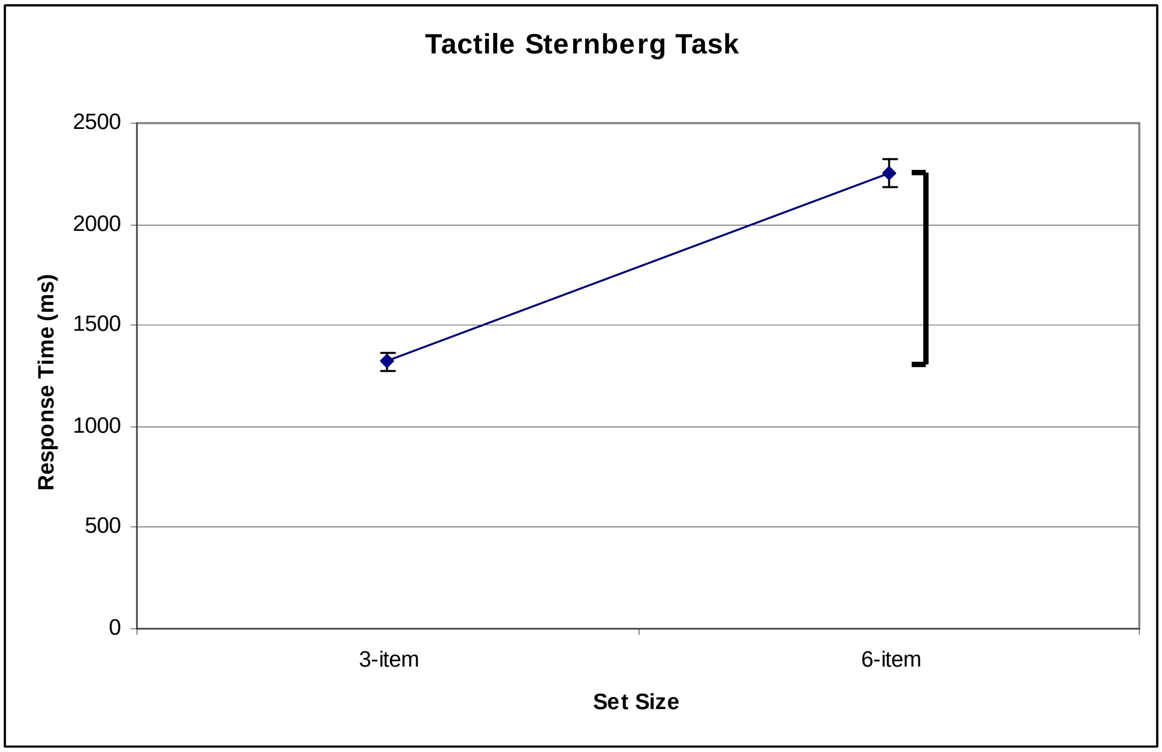

Figure 17. Effects of set size on response times for tactile Sternberg task stimuli. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was no main effect of spatial grouping, $F(1, 58) = .128$, $p = .722$, partial $\eta^2 = .002$. However, there was an interaction between Sternberg task set size and spatial grouping, $F(1, 58) = 36.708$, $p < .001$, partial $\eta^2 = .388$ (please see Table 7 and Figure 18). Subsequent pair-wise comparisons with a Bonferroni correction to account for type-I error inflation show that grouping stimuli slowed response times to stimuli in the 3-items sets. However, for 6-items sets, grouping stimuli improved response times over ungrouped stimuli.

Table 7. *Effects of set size and spatial grouping on tactile Sternberg task.*

				95% Confidence Interval	
Spatial Grouping	**Set Size**	***M***	***SD***	**Lower Bound**	**Upper Bound**
3-item	**Grouped**	1460.335	363.0791	1327.644	1593.027
	Ungrouped	1180.427	363.0791	1047.735	1313.119
6-item	**Grouped**	2072.823	542.2508	1874.651	2270.995
	Ungrouped	2429.263	542.2508	2231.091	2627.435

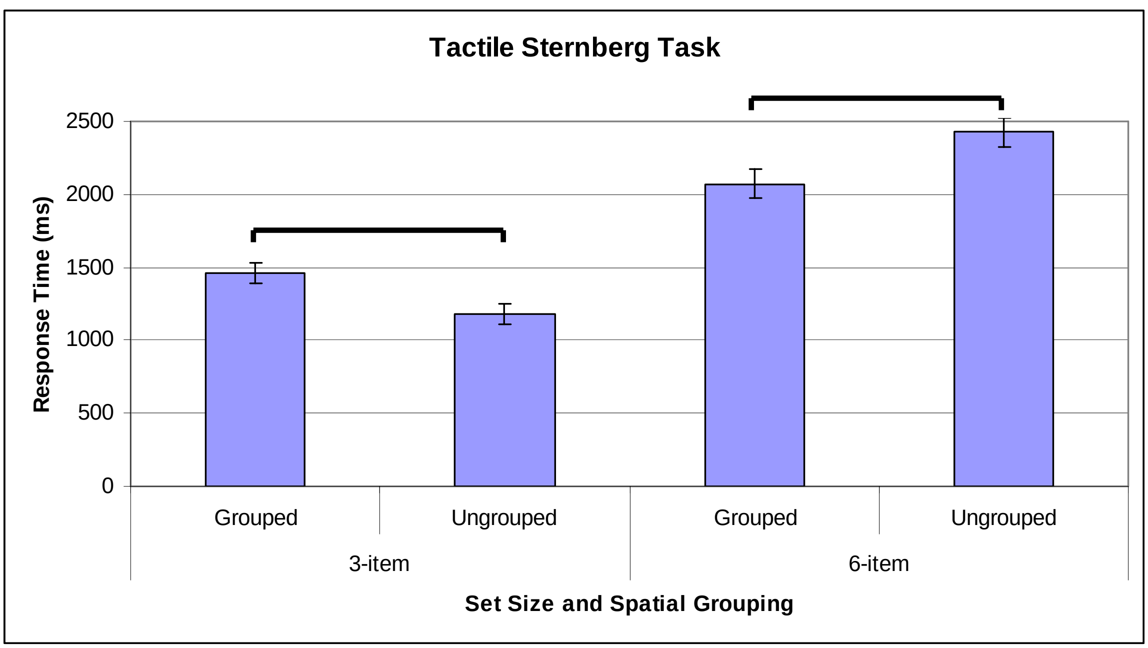

Figure 18. Effects of set size and spatial grouping on tactile Sternberg task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was a significant main effect of WM loading task condition on the tactile Sternberg task, $F(3, 174) = 3.336$, $p < .05$, partial $\eta^2 = .054$. The mean response times for the tactile-alone condition, as well as its pairings with the visual, auditory, and tactile WM loading tasks can be found in Table 8 (also see Figure 19). Subsequent pair-wise comparisons (LSD) were examined to determine locations of the differences. In comparing visual WM loading against the baseline, there was no significant difference. However, response times did significantly increase from baseline while performing a concurrent auditory WM loading task. There was a similar increase from baseline while performing the tactile WM loading task. There was no significant interaction between WM loading task condition and set size, $F(1, 174) = 1.619$, $p = .187$, partial $\eta^2 = .027$. Please also refer to Figure 20.

Table 8. *Response times for tactile Sternberg task by WM loading task condition.*

WM Loading Task Type	***M***	***SD***	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
None	1691.039	419.657	1582.591	1799.487
Visual	1766.038	493.873	1638.411	1893.665
Auditory	1827.433	539.1331	1688.11	1966.756
Tactile	1858.338	519.5378	1724.078	1992.597

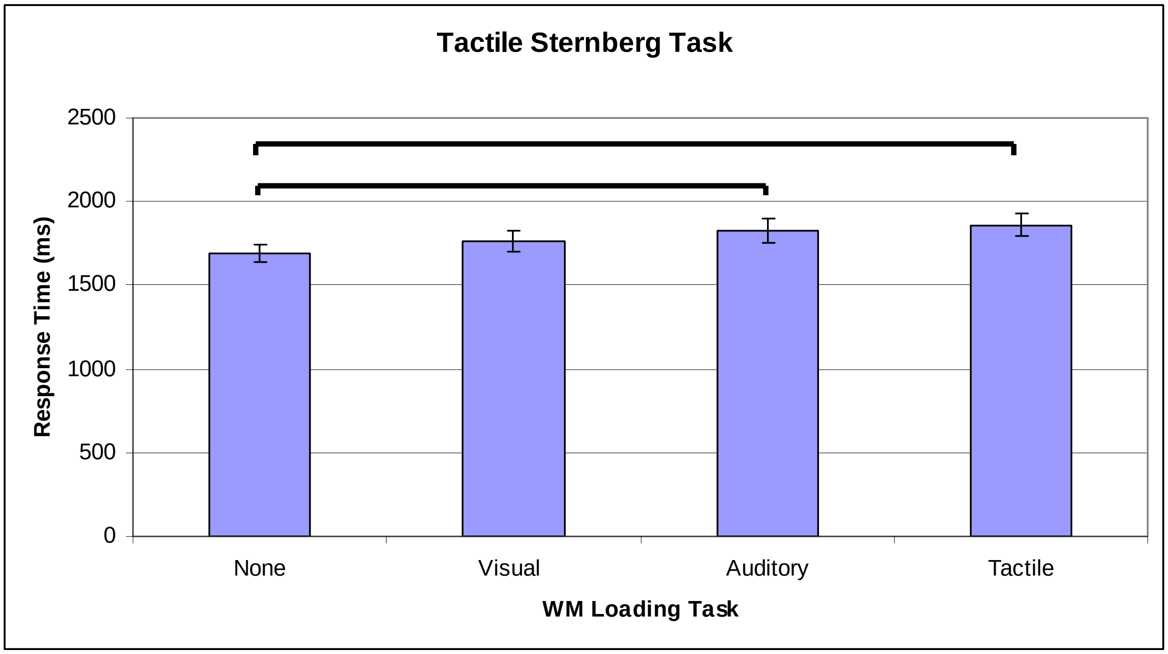

Figure 19. Response times for tactile Sternberg task by WM loading task condition. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

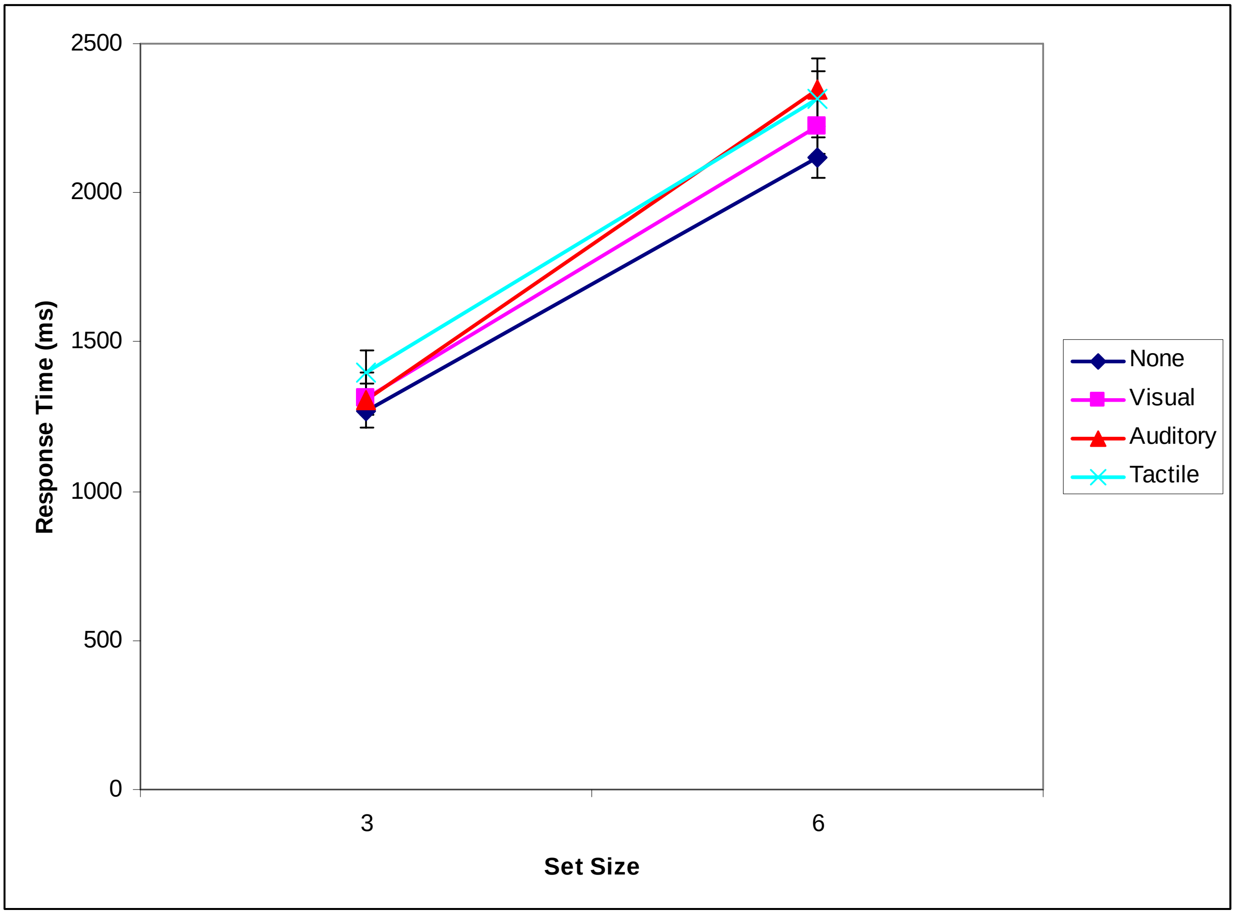

Figure 20. Effects of set size and WM loading task condition on tactile Sternberg task.

Analysis of Response Time Slopes

The response time slopes for each facet of the Sternberg task data. This includes the slopes for the baseline visual, auditory, and tactile (with no WM loading task), as well as each with the WM loading task (visual, auditory, and tactile). Slopes were computed only for the ungrouped data. Chi and Chase (1972) found that response times for set sizes similar to those used in this experiment were linear in nature. Given the spatial factor of the grouped data and only two set size points (3-item and 6-item), linearity cannot be assumed to compute slope.

The slope information is valuable as it suggests the level of interference as set sizes increase. For example, asking an office assistant named Bill to make copies of a large document will take a set amount of time due to the speed of the copier. Asking Bill to then make copies of another large document while copying the first is going to take a long time given that the originals have to removed and switched accordingly. If we plot the time it takes Bill to copy one document versus the time it takes to simultaneously copy additional documents, we will show that the multiple-copies slope is higher than the single-copy baseline. However, if we take our second document down the hall to Anne's copier, then the slopes for obtaining both documents at the end our parallel. This is due to the fact that both our working at the same pace (assuming the copiers are equal) and the additional time is only due to initially walking further down the hall to distribute the work. This same argument applies to multiple, independent neural processes. For example the visual Sternberg task baseline represents Bill's copying task. If we then add a visual WM loading task, then we may see the same effect as giving Bill additional copying tasks. If we instead add an auditory WM task, then this might be the same as asking Anne to make the second set of copies. It may take additional time to encode, but if the processes are independent, then the angle of the slope should not change. If processes do interfere with one another, then the slope representing the additional cognitive load should significantly diverge from the baseline slope.

Slopes for each participant in the spatially ungrouped condition were computed. These were computed using the following equation:

(RT6 – RT3) / (6 – 3)

RT6 denotes the response time for the 6 item sets and RT3 denotes response times for the 3-item sets. This numerator is the change in the response times. The denominator represents the change in the set size. The computed slope information can be found in Table 9. Paired-samples t-tests were then performed on the computed slopes to ascertain differences between baseline levels, as well as comparison between a modality baseline and its pairings with the WM loading tasks.

Table 9. *Sternberg task computed response time slopes.*

Condition	Modality	*N*	*M*	*SD*
Baseline (no load)				
	Visual Sternberg Task	30	336.8587	153.7991
	Auditory Sternberg Task	30	274.7952	119.2419
	Tactile Sternberg Task	30	389.6517	167.6733
Visual Sternberg Task				
	Visual WM task	30	325.167	187.1767
	Auditory WM task	30	402.4239	230.1596
	Tactile WM task	30	303.2918	198.4667
Auditory Sternberg Task				
	Visual WM task	30	250.5416	162.7377
	Auditory WM task	30	342.2289	238.379
	Tactile WM task	30	308.3374	208.8364
Tactile Sternberg Task				
	Visual WM task	30	381.9548	196.9973
	Auditory WM task	30	477.5581	219.1084
	Tactile WM task	30	415.9498	190.5635

To account for type I error inflation, p-values were reduced for the comparisons among the baslines, p = (.05/3) = .017. There was a significant difference between the baseline visual and baseline auditory slopes, $t(29) = 2.941$, $p < .01$. The slope for the auditory baseline was significantly lower than the visual slope. There was a significant difference between the visual and tactile baseline slopes, $t(29) = -2.684$, $p < .017$. The visual slope was significantly lower than the tactile slope. There was also a significant difference between the auditory and tactile baseline slopes, $t(29) = -4.510$, $p < .001$, with the auditory baseline slope again lower than the tactile slope.

Each Sternberg task baseline modality was compared against its pairings with the WM loading task modalities. First, the visual Sternberg task baseline (no WM task) was compared against the pairings with the visual, auditory, and tactile WM tasks ($p = .05/3 = .017$). Paired-samples t-tests revealed no significant differences between the visual baseline slopes and the visual with the visual WM loading task, $t(29) = .364$, $p = .719$. There was no difference between the baseline and auditory WM task, $t(29) = -1.806$, $p = .081$, as well as no difference between the baseline and tactile WM task, $t(29) = .995$, $p = .328$.

A similar analysis was conducted on the auditory stimuli. No difference was found between the auditory baseline and pairing with the visual WM task, $t(29) = .711$, $p = .483$. There was also no difference between the auditory baseline and its auditory WM task pairing, $t(29) = -1.580$, $p = .125$. For the auditory baseline and subsequent pairing with the tactile WM task, there was no difference between the two slopes, $t(29) = -.934$, $p = .358$.

For the tactile Sternberg task, a similar pattern emerged with the paired-samples t-tests. There was no difference between the baseline-visual WM task comparison ($t(29) = .175$, $p = .862$), baseline-auditory WM task comparison ($t(29) = -2.417$, $p = .022$), and baseline-tactile WM task comparison ($t(29) = -4.510$, $p = .393$).

Correlations of Pre-tests with Sternberg Task Data

Bivariate correlations were obtained to examine the relationship of data from the pre-test measures with the Sternberg task response time data (see Appendix XZ for a table of these correlations). The paper folding test showed a significant correlation ($p < .05$) on 10 of 18 blocks of response time data in which participants were concurrently loaded with secondary WM task stimuli. A repeated-measures MANCOVA was performed, examining the within-subjects factors of Sternberg task set size (3-item vs. 6-item), Sternberg task modality (visual, auditory, tactile), and WM loading modality (visual, auditory, tactile) on Sternberg task response times. Spatial grouping of the Sternberg task stimuli (ungrouped vs. grouped) served as the between-subjects factor, and the paper folding test scores served as the covariate.

There was a main effect of set size, $F(1, 57) = 54.253$, $p < .001$, partial $\eta^2 = .488$. For these interlaced tasks, the 3-item sets yielded a mean of 1349.293 ($SD = 302.790$) ms, while performance with the 6-item sets was significantly slower ($M = 2168.643$, $SD = 498.616$). There was also a main effect for Sternberg task modality, $F(2, 56) = 3.662$, $p < .05$, partial $\eta^2 = .116$. Subsequent pair-wise comparisons with a Bonferroni correction showed a familiar pattern of results, with visual ($M = 1550.510$, $SD = 363.875$) faster than both auditory ($M = 1909.126$, $SD = 411.396$) and tactile ($M = 1817.270$, $SD = 428.902$). However, auditory and tactile did not differ significantly. There was no significant main effect for WM loading modality, $F(2,56) = .782$, $p = .463$, partial $\eta^2 = .027$.

There was also a significant 3-way interaction of set size, WM loading modality, and paper folding test score on Sternberg task response times, $F(2, 56) = 3.996$, $p < .05$, partial $\eta^2 = .125$. To further examine this interaction, a MANCOVA (with the within-subjects factor of WM loading modality and paper folding test scores as the covariate) was performed on each set size.

There were no significant interactions in the 3-items sets that compared WM loading modality and paper folding scores, $F(2, 57) = 1.810$, $p = .173$, partial $\eta^2 = .060$. There was also no main effect for WM task modality, $F(2, 57) = 1.515$, $p = .229$, partial $\eta^2 = .050$. As a covariate, paper folding test scores were found to be significant, $F(1, 58) = 10.625$, $p < .005$, partial $\eta^2 = .155$.

A similar analysis of the 6-items sets yielded parallel findings, with no main effect for WM task modality or interaction with paper folding scores. There was again a significant effect for paper folding as a covariate, $F(1, 58) = .138$, $p = .01$, partial $\eta^2 = .110$.

WM Loading Task Accuracy

Percent correct was determined for each presented set of working memory loading stimuli. The baseline performance levels for the visual, auditory, and tactile WM loading tasks was computed and subjected to a repeated-measures ANOVA. Analyses were conducted using SPSS 11.5® and Microsoft Excel® with $\alpha < .05$, unless otherwise stated. WM task modality for these baseline performances served as the independent variable. There was a significant main effect for WM loading task modality, $F(2, 118) = 49.885$, $p < .001$, partial $\eta^2 = .458$. Sphericity was violated in this test, so the Greenhouse-Geisser df-corrected model was examined and it yielded identical results. Subsequent pairwise comparisons with a Bonferroni correction showed that visual (M = .928, SD = .108) WM task performance was better than tactile (M = .852, SD = .101) WM task performance. Auditory (M = .998, SD = .001) WM task performance was better than both visual and tactile WM task performances.

To further examine the results, the following analyses focus on the individual WM loading task modalities. The focus of this work is to determine the effects of the primary task factors on each type of WM loading task modality. The within-subjects factors were Sternberg task probe modality (none, visual, auditory, and tactile) and memory set size (3-item and 6-item sets). The between subjects factors examined order effects for presentation combinations of the set sizes and task interlacing, as well as spatial grouping of stimuli. Analyses were conducted using SPSS 11.5® and Microsoft Excel® with $\alpha < .05$, unless otherwise stated. Table 9, Table 10, and Table 11 show the data for these factors across visual, auditory, and tactile WM loading tasks, respectively.

Table 10. *Percents correct for Visual WM Task.*

Sternberg Task Interference	Set Size	Spatial Grouping	*M*	*SD*	95% Confidence Interval	
					Lower Bound	Upper Bound
Visual	3	Grouped	0.780	0.256	0.686	0.873
		Ungrouped	0.862	0.256	0.769	0.956
	6	Grouped	0.789	0.228	0.706	0.873
		Ungrouped	0.832	0.228	0.748	0.915
Auditory	3	Grouped	0.724	0.275	0.624	0.825
		Ungrouped	0.821	0.275	0.721	0.922
	6	Grouped	0.773	0.264	0.676	0.869
		Ungrouped	0.795	0.264	0.699	0.891
Tactile	3	Grouped	0.777	0.237	0.690	0.864
		Ungrouped	0.840	0.237	0.754	0.927
	6	Grouped	0.690	0.257	0.596	0.784
		Ungrouped	0.861	0.257	0.767	0.955
None	3	Grouped	0.902	0.128	0.856	0.949
		Ungrouped	0.947	0.128	0.900	0.994
	6	Grouped	0.911	0.105	0.873	0.949
		Ungrouped	0.950	0.105	0.912	0.988

Table 11. *Percents correct for Auditory WM task.*

Sternberg Task Interference	Set Size	Spatial Grouping	*M*	*SD*	95% Confidence Interval	
					Lower Bound	Upper Bound
Visual	3	Grouped	0.953	0.112	0.912	0.994
		Ungrouped	0.960	0.112	0.919	1.001
	6	Grouped	0.893	0.205	0.819	0.968
		Ungrouped	0.880	0.205	0.805	0.955
Auditory	3	Grouped	0.973	0.099	0.937	1.009
		Ungrouped	0.933	0.099	0.897	0.969
	6	Grouped	0.900	0.186	0.832	0.968
		Ungrouped	0.867	0.186	0.799	0.935
Tactile	3	Grouped	0.873	0.166	0.813	0.934
		Ungrouped	0.927	0.166	0.866	0.987
	6	Grouped	0.947	0.182	0.880	1.013
		Ungrouped	0.833	0.182	0.767	0.900
None	3	Grouped	1.000	0.012	0.996	1.004
		Ungrouped	0.996	0.012	0.991	1.000
	6	Grouped	1.000	0.012	0.996	1.004
		Ungrouped	0.996	0.012	0.991	1.000

Table 12. *Percents correct for Tactile WM task.*

Sternberg Task Interference	Set Size	Spatial Grouping	*M*	*SD*	95% Confidence Interval	
					Lower Bound	Upper Bound
Visual	3	Grouped	0.667	0.206	0.591	0.742
		Ungrouped	0.840	0.206	0.765	0.915
	6	Grouped	0.707	0.227	0.624	0.790
		Ungrouped	0.680	0.227	0.597	0.763
Auditory	3	Grouped	0.693	0.197	0.621	0.765
		Ungrouped	0.727	0.197	0.655	0.799
	6	Grouped	0.767	0.197	0.695	0.839
		Ungrouped	0.787	0.197	0.715	0.859
Tactile	3	Grouped	0.713	0.186	0.645	0.781
		Ungrouped	0.820	0.186	0.752	0.888
	6	Grouped	0.753	0.217	0.674	0.833
		Ungrouped	0.727	0.217	0.647	0.806
None	3	Grouped	0.856	0.107	0.816	0.895
		Ungrouped	0.864	0.107	0.825	0.904
	6	Grouped	0.843	0.108	0.804	0.883
		Ungrouped	0.844	0.108	0.805	0.884

Visual WM Loading Task

There was a significant main effect of Sternberg probe modality on visual WM task performance, $F(3, 56) = 16.784$, $p < .001$, partial $\eta^2 = .473$. Subsequent pair-wise comparisons with a Bonferroni correction showed that the baseline performance level significantly differed from concurrent performance with all three Sternberg task modalities. However, the effects of concurrent Sternberg task modalities did not differ from one another (see Figure 21).

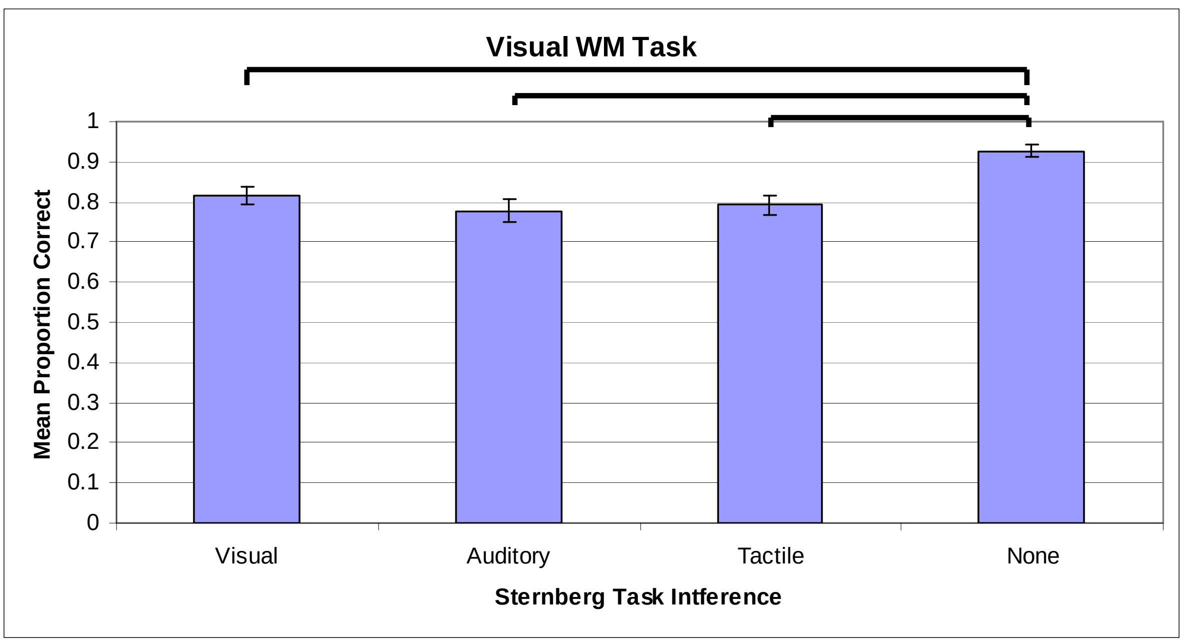

Figure 21. Effects of Sternberg task condition on visual WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

There was no main effect for Sternberg task set size on visual WM loading task performance, $F(1, 58) = .126$, $p = .724$, partial $\eta^2 = .002$ (see Figure 22). There was a main effect for spatial grouping, $F(1, 58) = 4.038$, $p < .05$, partial $\eta^2 = .065$. The visual WM loading task performance was significantly lower for grouped Sternberg task stimuli than for ungrouped Sternberg task stimuli (please see Figure 23).

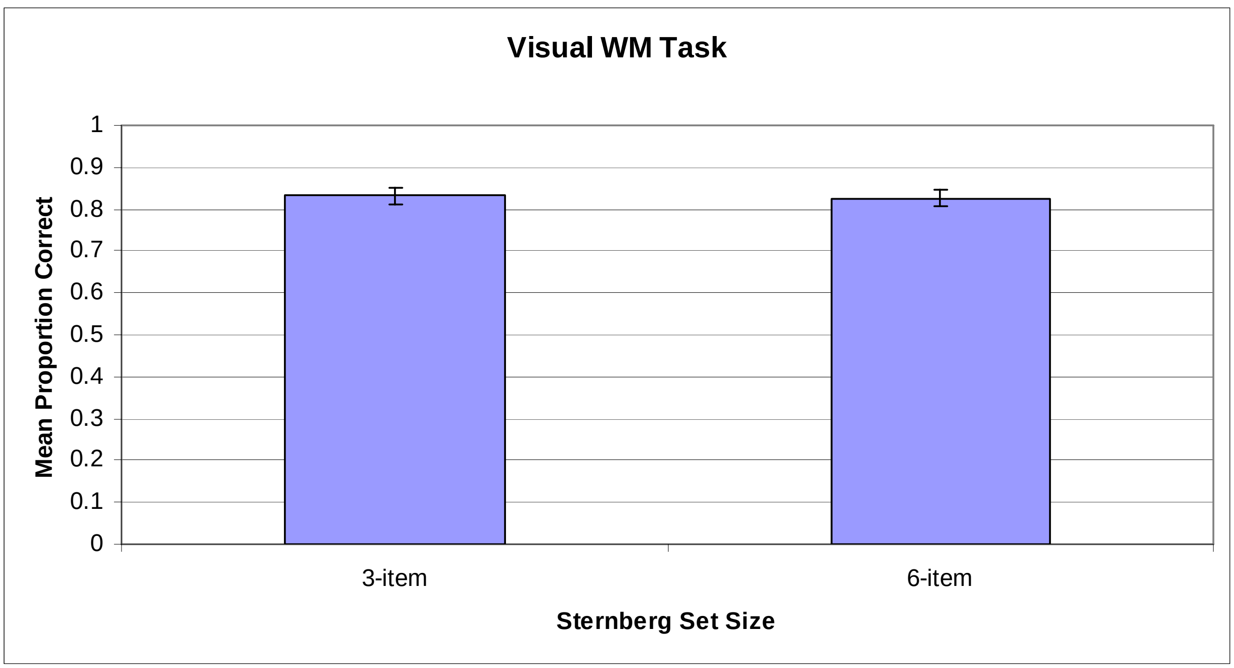

Figure 22. Effects of Sternberg task set size on visual WM loading task. Error bars represent standard error.

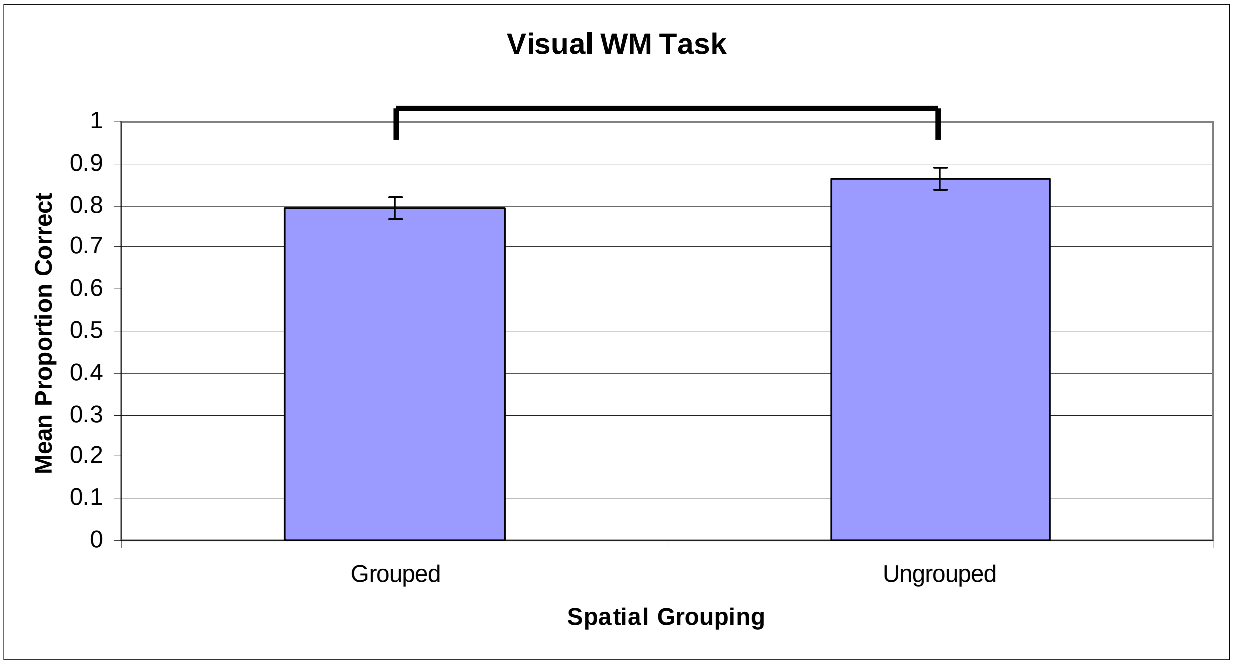

Figure 23. Effects of Sternberg task spatial grouping on visual WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

Auditory WM Loading Task

There was a significant main effect of Sternberg probe modality on auditory WM task performance, $F(3, 56) = 17.294$, $p < .001$, partial $\eta^2 = .481$. Subsequent pair-wise comparisons with a Bonferroni correction showed that the baseline performance level significantly differed from concurrent performance with all three Sternberg task modalities. However, the effects of concurrent Sternberg task modalities did not differ from one another. There was a main effect for Sternberg task set size on auditory WM loading task performance, $F(1, 58) = 9.723$, $p < .005$, partial $\eta^2 = .144$. 6-item Sternberg task sets posed more interference with the auditory WM loading task than 3-item sets. There was no main effect for spatial grouping, $F(1, 58) = .899$, $p = .347$, partial $\eta^2 = .015$.

There was a significant three-way interaction of Sternberg task modality, Sternberg task set size, and Sternberg spatial grouping on auditory WM loading task performance, $F(3, 56) = 3.372$, $p < .05$, partial $\eta^2 = .153$. To further examine this relationship, an additional analysis was run for each level of Sternberg task modality (visual, auditory, and tactile). The baseline was excluded as it would be impossible for the spatial grouping and set size to affect the isolated baseline performance. The independent variables were set size (within-subjects) and spatial grouping (between-subjects) with a new alpha level of .017 (.05/3) to account for Type I error inflation.

The first follow-up analysis examined the impact of set size and spatial grouping on auditory WM loading task performance while concurrently performing the visual Sternberg recall task (see Figure 24). There was a significant main effect of set size, $F(1, 58) = 9.723$, $p < .005$, partial $\eta^2 = .144$. For the concurrently performed auditory WM task and visual Sternberg task, the 6-item Sternberg sets showed greater interference effects. There was no main effect for spatial grouping, $F(1, 58) = .899$, $p = .347$, partial $\eta^2 = .015$.

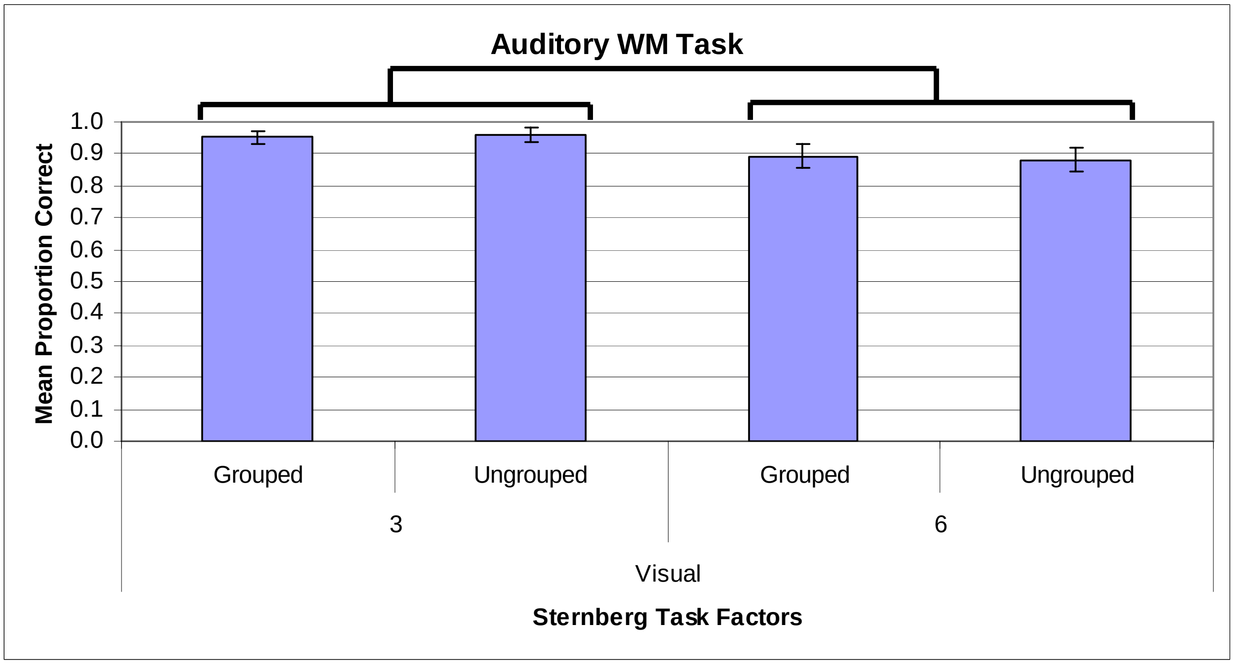

Figure 24. Effects of visual Sternberg task set size and spatial grouping on auditory WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

The second follow-up analysis examined the impact of set size and spatial grouping on auditory WM loading task performance while concurrently performing the auditory Sternberg recall task. There was a significant main effect of set size, $F(1, 58) = 7.149$, $p < .017$, partial $\eta^2 = .110$ (see Figure 25). For the concurrently performed auditory WM task and auditory Sternberg task, the 6-item Sternberg sets showed greater interference effects. There was no main effect for spatial grouping, $F(1, 58) = 1.696$, $p = .198$, partial $\eta^2 = .028$.

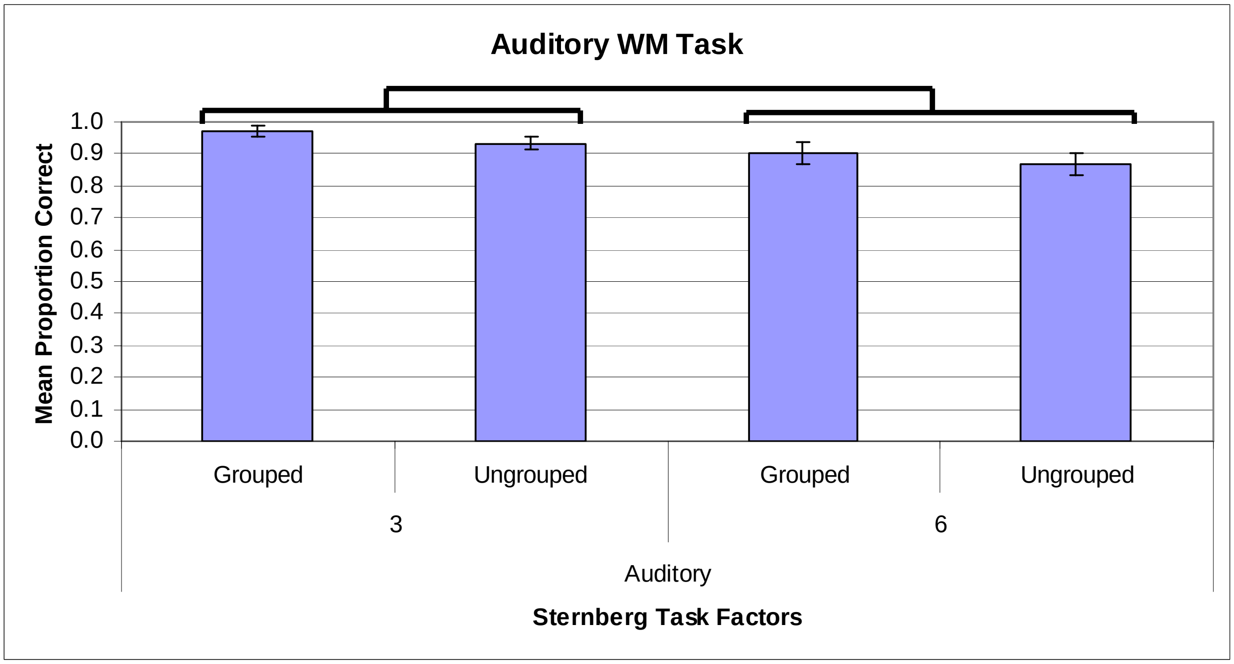

Figure 25. Effects of auditory Sternberg task set size and spatial grouping on auditory WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

The third follow-up analysis examined the impact of set size and spatial grouping on auditory WM loading task performance while concurrently performing the tactile Sternberg recall task (see Figure 26). There was no significant main effect of set size, $F(1, 58) = .149$, $p = .701$, partial $\eta^2 = .003$. There was also no main effect for spatial grouping, $F(1, 58) = .666$, $p = .418$, partial $\eta^2 = .011$. There was a significant interaction of set size and spatial grouping, $F(1, 58) = 10.339$, $p < .002$, partial $\eta^2 = .151$. Subsequent pair-wise comparisons with a Bonferroni correction showed that ungrouped, 6-item spatial tactile sets hindered auditory WM task performance more than grouped, 6-item spatial tactile sets. Increasing the set size hindered performance more on the ungrouped condition, but it had no effect on the grouped stimuli (please see Figure 26).

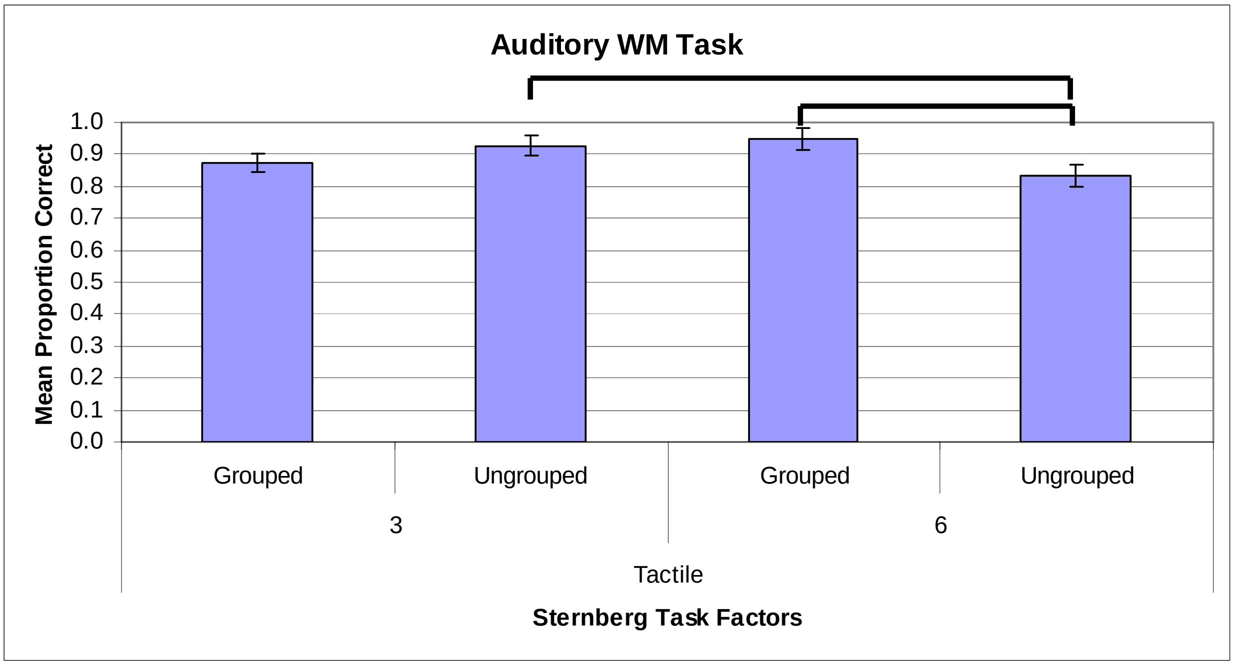

Figure 26. Effects of tactile Sternberg task set size and spatial grouping on auditory WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

Tactile WM Loading Task

There was a significant main effect of Sternberg probe modality on tactile WM task performance, $F(3, 56) = 14.873$, $p < .001$, partial $\eta^2 = .443$. Subsequent pair-wise comparisons with a Bonferroni correction showed that the baseline performance level significantly differed from concurrent performance with all three Sternberg task modalities. However, the effects of concurrent Sternberg task modalities did not differ from one another. There was no main effect for Sternberg task set size on tactile WM loading task performance, $F(1, 58) = .388$, $p = .536$, partial $\eta^2 = .007$. There was no main effect for spatial grouping, $F(1, 58) = 2.150$, $p = .148$, partial $\eta^2 = .036$.

There was a significant three-way interaction of Sternberg task modality, Sternberg task set size, and spatial grouping on auditory WM loading task performance, $F(3, 56) = 3.008$, $p < .05$, partial $\eta^2 = .139$. To further examine this relationship, an additional analysis was run for each level of Sternberg task modality (visual, auditory, and tactile). The baseline was excluded as it would be impossible for the spatial grouping and set size to affect the isolated baseline performance. The independent variables were set size (within-subjects) and spatial grouping (between-subjects) with a new alpha level of .017 (.05/3) to account for Type I error inflation.

The first follow-up analysis examined the impact of set size and spatial grouping on tactile WM loading task performance while concurrently performing the visual Sternberg recall task (see Figure 27). There was no significant main effect of set size, $F(1, 58) = 2.619$, $p = .111$, partial $\eta^2 = .043$. There was no main effect for spatial grouping, $F(1, 58) = 3.065$, $p = .085$, partial $\eta^2 = .050$. There was a significant interaction of set size and grouping, $F(1, 58) = 7.274$, $p < .01$, partial $\eta^2 = .111$. Subsequent pair-wise comparisons with a Bonferroni correction showed that spatially grouped, 3-item visual sets significantly hindered performance on tactile WM loading performance more than ungrouped, 6-item sets.

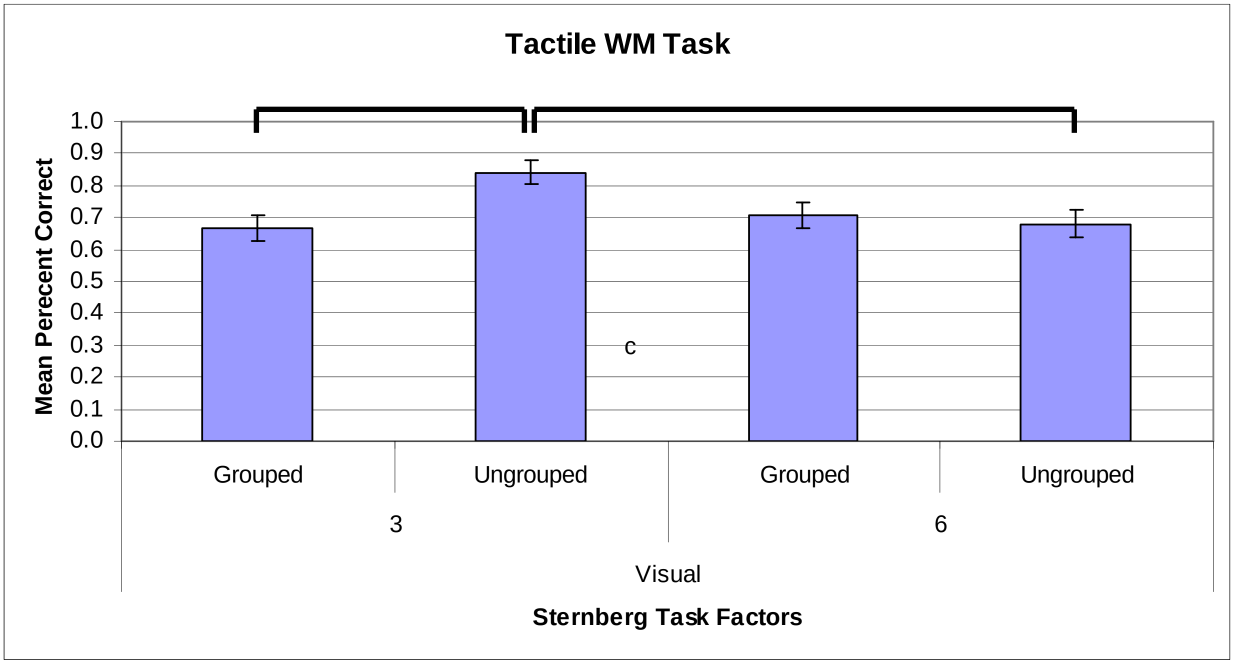

Figure 27. Effects of visual Sternberg task set size and spatial grouping on tactile WM loading task. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

The second follow-up analysis examined the impact of set size and spatial grouping on tactile WM loading task performance while concurrently performing the auditory Sternberg recall task (see Figure 28). There was no significant main effect of set size due to the Type I error correction, $F(1, 58) = 4.758$, $p = .033$, partial $\eta^2 = .076$, but it did trend toward significance. There was no main effect for spatial grouping, $F(1, 58) = .431$, $p = .514$, partial $\eta^2 = .007$.

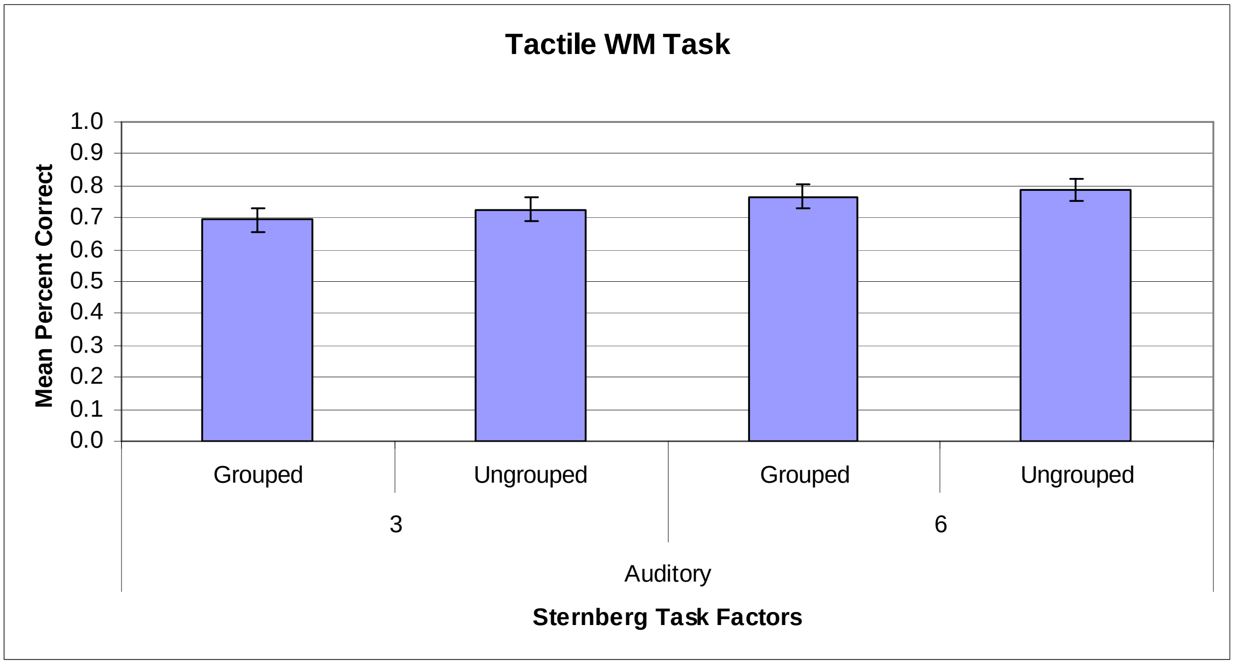

Figure 28. Effects of auditory Sternberg task set size and spatial grouping on tactile WM loading task. Error bars represent standard error.

The third follow-up analysis examined the impact of set size and spatial grouping on tactile WM loading task performance while concurrently performing the tactile Sternberg recall task (see Figure 29). There was no significant main effect of set size, $F(1, 58) = .685$, $p = .411$, partial $\eta^2 = .012$. There was no main effect for spatial grouping, $F(1, 58) = .950$, $p = .334$, partial $\eta^2 = .016$. There was a non-significant trend for an interaction between set size and spatial grouping, $F(1, 58) = 4.284$, $p = .043$, partial $\eta^2 = .069$.

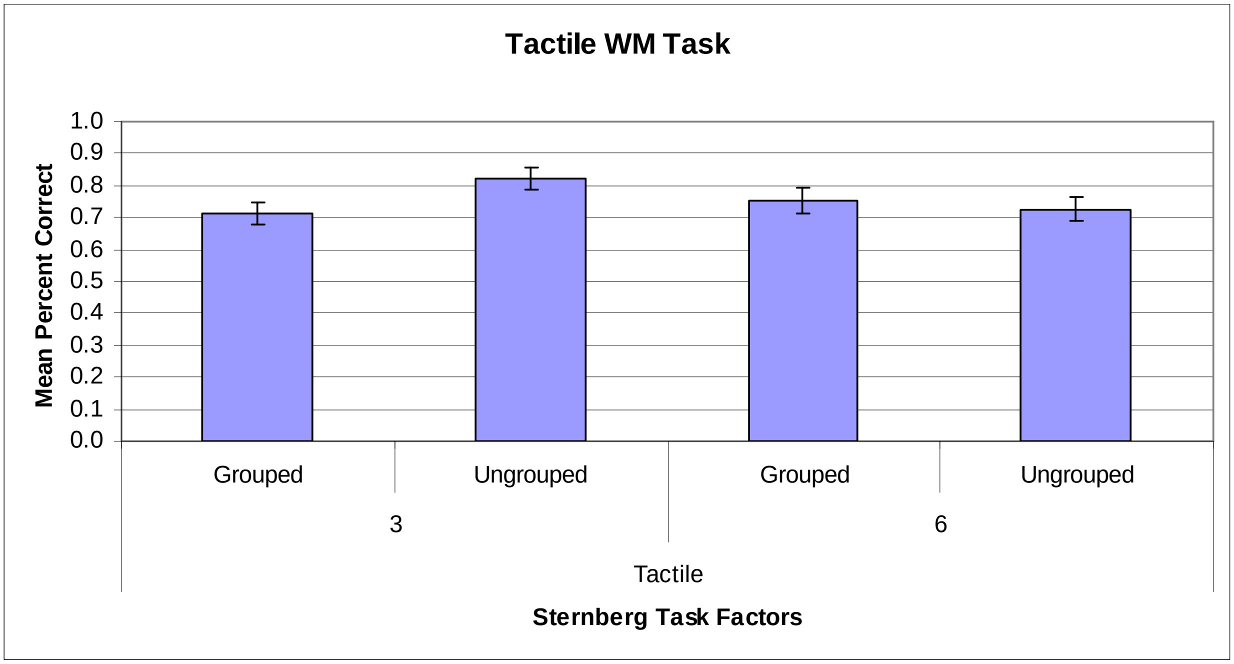

Figure 29. Effects of tactile Sternberg task set size and spatial grouping on tactile WM loading task. Error bars represent standard error.

Encoding Difficulty

The experimenter also computed the total number of presentations required for each memory set for participants to reach a satisfactory level of memorization to begin the experimental trials. A two-tailed, independent samples t-test was performed on the mean number of presentation sets that were required to memorize a set of 3-item stimuli in either the spatially ungrouped or grouped conditions. A two-tail test was selected as no differences were expected in the 3-item sets. The test yielded no significant difference between the mean number of required presentations for memorization across the ungrouped (M = 3.095, SD = 0.301) and grouped (M = 3.047, SD = 0.218), $t(40) = .580$, $p = .560$. A one-tailed, independent samples t-test was performed on the mean number of presentation sets that were required to memorize a set of 6 item stimuli in either the spatially ungrouped or grouped conditions. A one-tail test was selected because in this instance it was hypothesized that the grouping of the stimuli would facilitate their encoding, leading to fewer required presentations when compared to the ungrouped stimuli. The test yielded a significant difference between the mean number of required presentations for memorization across the ungrouped (M = 4.142, SD = 1.153) and grouped (M = 3.523, SD = 0.981), $t(40) = 1.874$, $p < .05$. This finding provides support for hypothesis 7. Please see Figure 30 to illustrate these differences.

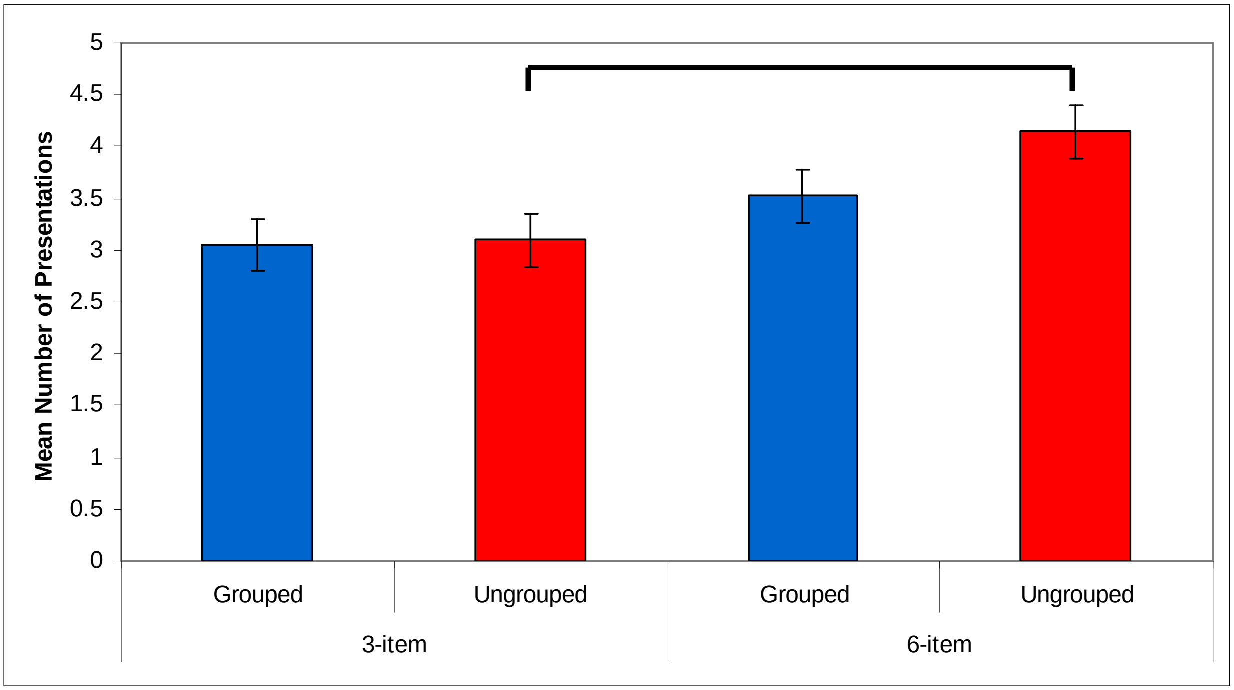

Figure 30. Encoding difficulty across set size length and spatial grouping. Error bars represent standard error. Linking bar represents significant difference ($p < .05$).

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION, & RECOMMENDATIONS

The primary motivation for this work was to determine how tactile information is handled in WM, particularly under disparate types of WM loadings. The following sections will address the aforementioned hypotheses and provide a general summary of findings, implications, limitations, and directions for future research.

General Discussion

Impacts on Visual Sternberg Task

Response times in the visual Sternberg task were significantly impacted by the set size that was used, with faster responses to 3-item versus 6-item sets. The spatial grouping factor was found to nearly impede performance on 3-item sets. This could be explained in the arrangement of the stimuli. In the ungrouped conditions, the stimuli were spread out across the visual ring, and other spatial organizational principles may have contributed to better performance. For instance, participants may have been able to create triangles out of the stimuli. This principle may have been more difficult to apply to the three grouped stimuli, as a triangle is not as readily apparent. For the 6-item sets, the grouped stimuli showed significant response time decreases. Here, the stimuli were able to be chunked according to spatial grouping factors, thereby facilitating performance.

Now turning to the impacts of the WM loadings upon the visual Sternberg task, there are interesting findings. Contrary to expectations, the visual WM task did not significantly increase response times from the baseline. This is likely due to how participants were utilizing the information for each task. In the visual Sternberg baseline, the input is visual but the participant is using the information as a cue to retrieve ordered information. This retrieval of ordered information may significantly impact the temporal processing for sequential information, even though the input is vision. Although participants showed that received the visual WM task information sequentially, they may have been able to combine the elements into a single visuo-spatial representation, thus removing the sequential information. This type of processing would no longer impact the sequential processing needed for the Sternberg task. For the auditory WM task, sequential (or temporal) processing is heavily utilized to maintain and retrieve the verbal stimuli. This would impact the processing normally associated with the Sternberg task, even though the inputs are different. The same argument holds for the tactile WM loading task as well. If a unified spatial representation was not generated for the stimuli, then the impact would be more upon the sequentially-based temporal processing.

This leads to a dissociation between the types of processing (spatial versus temporal) and the inputs normally associated with each, specifically, vision for spatial and audition for temporal. These results suggests that while simultaneous visual inputs may indeed interfere, multiple visual inputs into memory may not interfere as much based upon the underlying processes used. However, while the visual Sternberg task information may have used more temporal processing features, the spatial information was not lost, as seen with the impacts of spatial grouping upon response time performance.

Impacts on Auditory Sternberg Task

For the auditory Sternberg task, set-size did significantly impact response times. Again, responses were faster for stimuli in 3-item sets as opposed to 6-item sets. However, the spatial grouping of the encoded stimuli did not have an impact on responses to auditory Sternberg trials. This suggests that while the visual, auditory, and tactile information was encoded together, a single representation was not formed because the auditory did not reap the benefits of the spatial grouping.

Regarding the impacts of the WM loading tasks on the auditory Sternberg task, these findings are consistent with the interpretation of the results from the visual WM task. In comparing the auditory Sternberg task baseline with the visual WM loading task there are no significant differences in response times. When the auditory and tactile WM tasks were imposed, then responses times significantly increased from the baseline levels. This suggests once again that the visual WM task required different processing, which did not interfere with performing the auditory Sternberg task. The auditory and tactile tasks did utilize the same processing, as evidenced by the increased in response times. The auditory and tactile WM tasks were using more temporal processing that preserved sequence order, while the visual WM task was able to be handled using spatial processing.

Impacts on Tactile Sternberg Task

As with the visual and auditory versions, set-size did significantly impact response times for the tactile Sternberg task. Again, responses were faster for stimuli in 3-item sets as opposed to 6-item sets. As with vision, the spatial grouping of the encoded stimuli had a significant impact on responses to tactile Sternberg trials. For 3-items sets, responses to ungrouped stimuli were faster than those for grouped stimuli. For the 6-item sets, the pattern was reversed. Here ungrouped stimuli required longer response latencies than grouped stimuli. This suggests that although the stimuli, the spatial information was not lost for tactile stimuli, despite the sequential processing required for the Sternberg task. If the stimuli had been completely recoded into a sequential representation, then the spatial grouping factor should have affected the response time.

In examinations of the WM task impact, a visual WM task did not substantially increase response time from the baseline level. For auditory and tactile WM tasks, there was a significant increase from the baseline level. This suggests that the processing requirements for these two tasks did substantially interfere with performing the Sternberg recall task.

Impacts on Visual WM Loading Task

The accuracy results from the visual WM task fit the interpretation put forth for the pattern seen in the Sternberg task response times. The set size of the Sternberg task did not impact performance on the visual WM task. If a single spatial representation was implemented, then the temporal processing associated with the changes in set size would not influence the spatial processing. The input modality of the Sternberg task stimuli did not impact accuracy for the visual WM task. While the presence of the Sternberg task did lower accuracy from baseline, there was no differential effect based upon the input modality. However, spatial grouping of the Sternberg task stimuli did affect the visual WM loading task, with grouped stimuli lowering accuracy when compared to ungrouped stimuli. Again this suggests that the type of processing occurring (overlapping spatial demands) was the key factor.

Impacts on Auditory WM Loading Task

For the auditory WM loading task, there was no main effect of Sternberg task input modality on accurate recall of the verbal stimuli. 6-item sets showed significantly higher interference than 3-item Sternberg sets (for vision and audition). However, the picture is a little less clear for the impact of the tactile Sternberg task. Here, ungrouped 6-item stimuli yielded worse performance on the auditory WM task than then grouped 6-item sets. Set size did affect the spatially ungrouped condition, with worse performance for the larger set size. This again shows, with the visual and auditory Sternberg counterparts, that the increased temporal demands for the larger set sizes interferes more with the temporal processing necessary to adequately perform the auditory WM task. However, the tactile Sternberg task is unique in that spatially grouping did allows participants to effectively spatially chunk the information so that set size did not impact performance on the auditory WM task.

Impacts on Tactile WM Loading Task

The impacts upon the tactile WM loading task are interesting as well. In breaking down the interaction across the Sternberg task modalities, spatially grouping the stimuli facilitated the chunking of the information and removed the impact of set size upon the tactile WM task for the grouped stimuli. For the ungrouped visual stimuli, the larger set size significantly impacted the tactile WM task performance. Without the spatial organizing principle in play, the increased demands upon temporal processing hindered performance on this task. Spatial grouping did not affect the impact of the auditory Sternberg task on the tactile WM task. There was a non-significant trend for the impact of set size, with the larger set size nearly hindering performance on the tactile WM task. For the impact of the tactile Sternberg task, the pattern of the set size and spatial grouping factors was similar to that for its visual Sternberg counterpart. However, once the alpha level was constrained for multiple tests, this failed to reach statistical significance.

A Place for Tactile

Based on the reviewed literature and the findings of this experiment, it appears that there is a shared place for tactile information in WM. The response times to 3-item tactile sets were rapid, falling between visual (the fastest) and auditory (the slowest). It would appear that for the 3-item sets, tactile information was able to draw upon the spatial characteristics normally reserved for visual representations to help speed responses. The spatial characteristics of the visual and tactile information allow for rapid encoding. The visual and tactile stimuli were able to benefit from simple coding of spatial relationships and not perform more complex abstraction into sequential verbal labels.

In the 6-item sets, responses to visual Sternberg stimuli remained the fastest. Auditory and tactile stimuli were now essentially equal in response times. The stimuli possibly relied on a sequential or temporal (non-spatial) system, however, the stimuli had to be recoded into this non-spatial format. For the longer sets, the tactile stimuli appeared to access the temporal (non-spatial) processing normally associated with verbal information. The spatial information of tactile stimuli was not completely lost. Spatially grouping the 6-item stimulus sets yielded faster response times for visual and tactile stimulus probes than for spatially ungrouped items. Responses to auditory stimuli did not change for grouped or ungrouped stimuli, even though the stimuli were encoded into memory using simultaneous visual, auditory, and tactile pathways. This suggests that while tactile information needed to use the sequential, temporally based information processing in the 6-item sets, the spatial information was not completely lost. Tactile information then serves as independent input, however it may then develop higher level connections with verbal and visual inputs for non-spatial and spatial processing.

Spatial and Temporal Processing

In terms of WM, the episodic buffer is typically formulated as a multimodal workspace (Baddeley, 2001). This workspace allows for the interplay between visual and verbal representations. However, tactile information has not traditionally been included in this formulation. The current work reinforces the multi-faceted nature of the episodic buffer, by adding tactile and suggesting that the facets involve more than vision and audition. Tactile information shares elements of both visual and auditory information. To account for this, perhaps it is best to remove the constraint of the visual or auditory input modality. Instead, it may be more beneficial from a research and design perspective to consider the elements of working memory only in terms of the types of processing that are occurring: spatial and temporal. The input modality labeling of WM subsystems is a bit misleading of these underlying processes. For instance, is the VSSP only visual in nature? Are congenitally blind individuals lacking a VSSP? Conversely, do the congenitally deaf lack a PL? Neurophysiological research with sensorially compromised patients tends to show the remarkable plasticity of neural organization (Kandel et al., 2000). The neurons from these individuals can be recruited to aid in the processing of information from the remaining functional senses. I would therefore propose that WM could be reformulated to reflect the underlying processes that are occurring irrespective of the sensory input. The VSSP might be more easily thought of as a purely *spatial sketchpad* (SpSP), as both auditory and tactile systems can also provide spatial information (e.g., Terrence, Brill, & Gilson, 2005; Spence, Pavani & Driver, 2000). Similarly, one could argue that the phonological loop may process sequences of discrete units of information with their semantic content. This could then be considered a more of a temporally based, *sequence loop* (SeL) that preserves sequence order information. Sensory input systems can now provide information to both spatial and semantic representations (see Figure 31 for an illustration of this reformulation).

As neurological evidence accumulates in support of the reformulated WM model (Baddeley, 2001), it is important to also consider revising the model to account for multimodal inputs that help to shape our perceptions of space and time. Spence and Driver (2004) show the interplay of information across modalities, with auditory and tactile information helping to shape the construction of perceived space. The presence of bimodal and trimodal neurons contribute to the picture of multiple inputs influencing the cognitive processes. With a sequence (timing) loop, no specific input modality is required, thereby providing an interesting framework to conduct additional cognitive performance and neurophysiological studies of patients with sensory loss. The same holds true for a spatial sketchpad. Removing the constraint of an input modality allows for the inclusion of research examining cross-modal constructions of space. This reformulation also assumes that the CE serves as attention to direct activities within these systems (Baddeley, 2001). The episodic buffer still provides a workspace for combining the meaning and spatial relationships of sensory data with prior experience drawn from LTM. This model also provides for the mediation of sensory data into WM by including the factors of environmental characteristics (informational displays and potential distractions/maskers) and individual characteristics (e.g., sensory loss). It also predicts the potential interference effects, irrespective of the input modality.

In terms of attentional resources, it fits well with theories dealing with multiple pools of resources (e.g., Navon & Gopher, 1979; Wickens, 1984, 2002). These theories were put forth to account for the wealth of dual-task data that was not explainable under a central capacity or unitary resource framework. However, in formulations such as Wickens' box model, the processing codes retain the spatial and verbal labels. It may be more accurate lose the verbal label, and focus more on the temporal nature of the stimuli. Verbal information is based on proper timing and ordering of sounds and words to imbue meaning. Free of the modality constraint, then these models are generally supported from this experiment. For example, although some of the Sternberg task stimuli were visual, the recall task is primarily based on the proper ordering of information. Hence, the visual WM task, which was highly spatial in nature, did not interfere with the visual Sternberg task stimuli more than the auditory and tactile Sternberg task stimuli.

While tactile information may not serve as an independent resource pool, it may serve as another access point for either spatial or temporal processing. The sequence loop and the spatial sketchpad help to capture the processing codes of the multiple resource theories, while retaining the connections with LTM and the episodic buffer. The inputs show that visual, auditory, and tactual information can access both the sequence loop and spatial sketchpad. In the context of the current experiment, auditory information was more significantly impacted by additional temporal processing demands and not the spatial factors. For vision and touch, temporal processing was accessed to complete the Sternberg task, however, the spatial characteristics were still preserved. This helps to support a dual coding hypothesis (Paivio, 1990), with input modalities being able to access both codes to varying degrees.

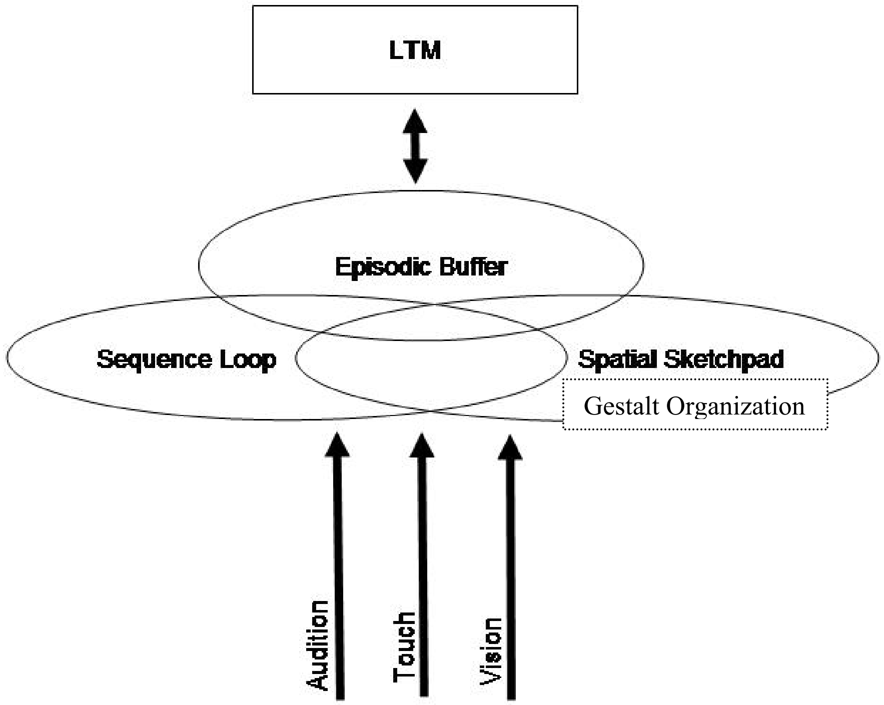

Figure 31. Proposed revision of WM model.

The Role of Gestalt Principles

This experiment ascertained the response time implications of using the Gestalt principle of spatial grouping. Other Gestalt principles and combinations of strategies may also provide additional benefits in multisensory display settings. The fields of graphic design and visual display design reap the benefits from applying grouping, good continuation, and symmetry. Auditory displays have also found benefits from applying these principles and recently, researchers are continuing to explore the role of Gestalt principles in haptics (Chang & Nesbitt, 2006).

The present research explored the application of one principle to a multisensory display. It facilitated encoding of complex information, as well as improved response times for those complex sets using spatial visual and spatial tactile displays. This indicates the performance, as well as the ease of organization, benefits of applying these principles to display design. Grouping similar items together as a single item may help to reduce the cognitive load, as each item does not need to be considered separately. The principle of good continuation can help to maintain the cognitive representation of a figure as it travels through space and moves behind additional objects. In this case, partially visible elements of a single entity are not considered separate, reducing the informational complexity. Symmetry may also help to reduce information complexity. If stimulus entities are grouped along identifiable axes, then one simply needs to encode the axis and not each individual entity. Under this framework, Gestalt principles may then facilitate the chunking of information (Chang et al., 2007). In terms of the proposed WM reformulation, Gestalt principles may operate in the spatial sketchpad. This is due to the disparity of the impact of the spatial grouping factors on the auditory Sternberg task stimuli. If information can be grouped or coded along spatial and stimulus feature factors, then that coding can help to reduce the overall informational complexity. As the computer metaphor is often applied to human cognitive processes (i.e., a central processor with STM serving as random access memory and LTM serving as a hard drive), Gestalt principles may then serve as compression algorithms for cognitive processes. Visual compression formats such as GIF reduce complex sets of information by coding for common, repeated elements. If Gestalt principles serve this purpose, it may help to explain the organizational appeal of their application in display design. These principles provide all the information, but in a manner that reduces overall complexity and perhaps lowers overall task demands for task such as Sternberg recall. Their application should be made with care. They did benefit provide response time benefits for visual and tactile Sternberg task performance. However, there was a decline in visual and tactile WM loading task performance when performance was concurrent with grouped versus ungrouped Sternberg task stimuli. This suggests that the performance benefit was a trade-off. Spatial processing facilitation on one task compromised spatial information processing on a concurrent WM task.

The proposed reformulation of WM includes the role of Gestalt principles in cognition, as the role of these principles is not contingent on the sensory information, but in the representations created in both the spatial sketchpad and the sequence loop. Gestalt principles that help to organize spatial complexity are not rooted solely in vision with this model. Tactually presented information can benefit from their application as well, as demonstrated in this experiment with complex patterns of information. Though spatial auditory displays were not part of the research methodology, the same principles may apply, as it is easier to selectively attend to spatially separated auditory communications (Brungart & Simpson, 2003).

In the context of this experiment, visual and tactile unisensory probes were able to benefit from spatial grouping of stimuli. Auditory probes did not show these benefits, though all stimuli were presented together and encoded simultaneously. This supports a dual coding interpretation of stimuli (Paivio, 1990). The verbal representations of the auditory stimuli did not show any benefits from being encoded with spatially grouped visual and tactile stimuli. This same interpretation fits with WM as well. With the multi-component system, verbal stimuli did not show any benefits from encoding with spatially grouped stimuli. This may suggest that the CE draws upon the spatial/sequence systems and not directly from the episodic buffer. If we assume that the episodic buffer includes all information combined together, then the auditory stimuli paired with spatially grouped visual/tactile stimuli should have experienced similar benefits.

However, if this multi-dimensional information did retain spatial and non-spatial facets, the lack of spatial gains for the auditory stimuli paired with grouped visual and auditory stimuli are consistent. Subsequent research will hopefully further elucidate these connections by examining the Gestalt principles governing visual and auditory stimuli and their application to somatosensory information.

Rapid Nature of Spatial Encoding

It is evident from the results in this work that spatial encoding and processing are rapid processes. For the smaller 3-item sets, responses to visual and tactile Sternberg sets were faster than auditory. More time was required for the 6-items sets, however, the responses to visual information remained significantly faster than auditory and tactile counterparts. In addition, the spatial factor of grouping was able to reduce response times in the visual and tactile 6-item sets. In these instances, the emphasis on spatial processing was able to recover some of the time necessary for the increased set sizes. The ungrouped stimuli did not have this spatial emphasis, therefore they relied heavily on the temporal processing as the only means to preserve the sequence order information.

Practical Implications

As display designers adopt multisensory displays to provide information to users (Oviatt, 2002), it is important to consider the cross-modal representations of displayed information in memory and how Gestalt organizational principles can facilitate cross-modal inputs. For example, the US Army uses arm and hand signals to convey commands in operational environments. Portable tactile displays can help to supplement these visual signals (Redden, Carstens, Pettit, Merlo, Stafford, Terrence, & Gilson, 2007). With these types of tactile displays, the visual arm and hand signals are recoded into patterns of vibrotactile actuator activity arrayed across the torso. Arbitrary vibrational patterns could have been selected to represent each arm and hand signal, however these patterns were developed to closely approximate the spatial characteristics of their visual counterparts. Thus, compatibility across modalities is accentuated. This helped facilitate their learning during field investigations with soldiers at obstacle courses (Redden et al., 2007). It is important to note that the visual signals utilized principles such as symmetry (both arms tapping the shoulders) and good continuation (an outstretched arm making a circle overhead). These aspects were captured in the design of the tactile equivalents. Synchronous vibrotactile "taps" to the immediate left and right positions corresponded with the taps to the shoulders. Consecutive activation of the tactors surrounding the body approximated the aforementioned circular motion of the arm. Preserving the useful application of Gestalt organizational principles in one display modality to a multimodal display setting can help facilitate the perception and acceptance of multisensory displays. They can also provide redundant channels of information if one sense is overwhelmed in a particular task context. The redundant information is then easily interpreted if it follows the same organizational properties as its counterparts in other sensory modalities. Encoding is then facilitated and does not result in additional interference in processing. For example, Ho et al. (2005) found increased benefits for spatially predictive auditory cues. Once again, the spatial compatibility across input modalities is accentuated in these instances. If the multisensory information provides useful spatial information across the senses, it can better direct cross-modal encoding, attention, and spatial processing. It is therefore important to consider the overall impact of including multiple display modalities so that they can reinforce one another and not detract. This includes examining the spatial and temporal factors for all related multisensory stimuli to ensure the construction of a compatible, meaningful, multimodal representation.

It is also important to note that the lack of a modality interaction between the visual Sternberg task probes and WM loading tasks has interesting design implications. Typically the modality inputs are of primary concern when determining the potential for task interference, as parsing information across the modalities can reduce interference (Wickens, 2002). However, in this experiment, overlapping visual tasks did not compromise performance more than overlapping visual and auditory tasks or overlapping visual and tactile tasks. One potential explanation for this is that the type of task for each caused a similar reduction of interference. In the Sternberg task, it was primarily a recall task, with very little encoding and rehearsal of new information. For the visual WM loading task, the participant may have not had to rehearse the individual elements and simply generated a pattern representing all of the stimuli, using a single chunk to handle the entire stimulus set. If this assumption is correct, there are potential implications for design of multisensory display systems. For multiple tasks systems, activities can engage a user with multiple visual task demands, but if both visual tasks do not require knowledge of sequential information, then they may be able to be time-shared or chunked effectively. Parsing display information across modalities can provide some alleviation from concurrent task performance decrements (Wickens, 2002), and it appears from these results that parsing information across processing types (spatial versus temporal (or sequential)) may also help to relieve performance decrements even for overlapping input modalities. If each input accesses a different processing type, then this can help facilitate performance in multi-task settings.

Limitations of Current Work

There are some limitations to the present research. First, only one Gestalt principle was included in the research design. Participants may have attempted to apply other principles such as symmetry, form, and good continuation to the stimuli in the Sternberg recall task. However, careful attention was paid during the stimulus development to minimize the impact of any other potential factors. It is also possible that the multimodal presentation of the stimuli may have produced unintended effects, such as each participant creating disparate multimodal representations. This possibility was considered, but for the present research, the multimodal presentation was selected because it helped to standardize how information was presented and encoded into LTM for the Sternberg task. Future work should examine matched and unmatched *uni*-modal combinations for encoding and retrieval, and the role of Gestalt principles upon performance. These studies, in conjunction with neuroimaging research, could help to paint a clearer picture of the cross-connectivity within neural structures, ascertain the implications for cognition and human performance, and facilitate compatibility in multimodal display design.

Also, there was a lack of interference during concurrent Sternberg recall and WM loading tasks for visual stimuli. The demand of the visual WM loading tasks may need to be increased in future studies to determine if the modality interference will occur for these types of tasks. This could be accomplished in several manners, including the use of stimuli that may overlap in features with primary task visual stimuli, increasing the number or complexity of the stimuli, or introducing additional constraints to inhibit the binding of the visual elements into a unified whole. Introducing incompatible spatial characteristics may also show the extent of these effects.

Future Avenues of Research

This modified Sternberg recall tasks provides a useful tool for examining the effects of stimulus and concurrent tasks on memory in a multisensory display setting. The potential permutations of the factors within this experimental paradigm may give rise to more detailed theoretical and practical implications for using multisensory displays. Key areas for future exploration include the impact of increased memory loads in unisensory and multisensory retrieval contexts. Another important area for exploration is the application of additional organizational principles and their compatibility across visual, auditory, and tactile inputs. As cross-modal neural connectivity is explored, how these principles can be implemented across visual, auditory (non-spatial and spatial displays), and tactile displays is of paramount importance to guide display design and improve user performance across operational settings. We must also employ these principles with care, particularly in multitasking contexts. The increased spatial processing for the grouped Sternberg stimuli hindered spatial processing for the visual WM task. Referring again to the computer analogy, compression algorithms reduce overall complexity, however there are additional central processing requirements that are needed in order to compress and then uncompress the data. It is important to also identify the costs associated in cognitive performance when applying these principles, and ensure that the costs in a multi-task setting do not outweigh the gains.

Summary

This work explored the role of spatial grouping, set size, and stimulus probe modality in a modified Sternberg recall task for multimodally encoded information. The effects of different WM loading task modalities were also examined. The Gestalt spatial organizing principle of grouping showed improvements in response times for visual and tactile stimulus probes with large set sizes and apparently allowed participants to effectively chunk the information. This research suggests that tactile information may use spatial characteristics typically associated with visual information, as well as sequential characteristics normally associated with verbal information. Based on these results, a reformulation of WM is warranted to remove the constraints of the input modality on processing types. The input modalities appear to all access both a spatial sketchpad and a temporally-based sequence loop. The effects of spatial grouping on the visual and tactile information show that as information is used across the processing types, the spatial characteristics are not lost. Spatial coding is also rapid and facilitates chunking, without the need to create an abstract representation for temporal processing as seen in verbal information. Tactile information appears to be able to draw upon both processing systems. Additional research is needed to continue to bridge the gap between cognitive performance and neurophysiological data, determine the Gestalt principle factors that guide informational representations across the senses, and guide multisensory display design. Baddeley (1996) describes working memory as providing “a crucial interface between perception, attention, memory, and action (p. 13472).” This work helps to elucidate the role of somatosensory information within this context. The Sternberg recall task and other memory tasks will hopefully continue to provide a sound methodology for additional multisensory research. It will also help to determine the neural underpinnings of multimodal perception and processing, and provide guidance for future multisensory display design.

APPENDIX A: IRB APPROVAL LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Exempt Review Status

From: **UCF Institutional Review Board**
FWA00000351, Exp. 5/07/10, IRB00001138

To: **Peter I Terrence**

Date: **September 19, 2007**

IRB Number: **SBE-07-05184**

Study Title: **Assessing Tactile Working Memory and Multimodal Loading**

Dear Researcher:

Your research protocol was reviewed by the IRB Chair on 9/18/2007. Per federal regulations, 45 CFR 46.101, your study has been determined to be **minimal risk for human subjects and exempt** from further IRB review or renewal unless you later wish to add the use of identifiers or change the protocol procedures in a way that might increase risk to participants. Before making any changes to your study, call the IRB office to discuss the changes. **A change which incorporates the use of identifiers may mean the study is no longer exempt, thus requiring the submission of a new application to change the classification to expedited if the risk is still minimal.** Please submit the Termination/Final Report form when the study has been completed. All forms may be completed and submitted online at https://iris.research.ucf.edu.

The category for which exempt status has been determined for this protocol is as follows:

2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures, or the observation of public behavior, so long as confidentiality is maintained.
   - (i) Information obtained is recorded in such a manner that the subject cannot be identified, directly or through identifiers linked to the subject, **and/or**
   - *(ii)* Subject's responses, if known outside the research would not reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability or reputation.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Janice Turchin on 09/19/2007 04:49:07 PM EDT

IRB Coordinator

APPENDIX B: DESCRIPTIVE STATISTICS FOR STERNBERG TASK RESPONSE TIMES (SEPARATED TASKS)

Table 13. *Descriptive Statistics for Separated Task Sternberg RT Data (Spatially Grouped Stimuli.*

Condition	*N*	*M*	*SD*	Skewness Statistic	Skewness SE	Kurtosis Statistic	Kurtosis SE
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	1221.745	647.666	2.647	0.427	9.064	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	1439.135	413.574	1.164	0.427	1.347	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	1491.890	660.828	1.567	0.427	2.836	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1144.564	431.214	1.731	0.427	3.323	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	1375.378	510.638	2.439	0.427	6.886	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	1318.935	520.975	2.357	0.427	7.716	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	1168.701	512.522	1.835	0.427	4.273	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	1464.199	466.192	1.323	0.427	1.669	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	1328.987	543.886	1.396	0.427	1.500	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	1588.140	484.449	0.780	0.427	-0.351	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	2009.700	512.821	0.549	0.427	-0.414	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	1950.626	546.634	0.867	0.427	0.194	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	1545.488	479.654	0.767	0.427	0.267	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	2014.298	492.020	0.426	0.427	-0.506	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	1842.654	567.226	0.799	0.427	1.325	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	1559.736	468.315	0.777	0.427	-0.068	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	2143.811	644.640	1.560	0.427	4.107	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	1936.066	564.791	0.750	0.427	0.828	0.833

Table 14. *Descriptive Statistics for Separated Task-Sternberg RT Data (Spatially Ungrouped Stimuli).*

Condition	*N*	*M*	*SD*	Skewness		Kurtosis	
				Statistic	*SE*	Statistic	*SE*
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	992.148	231.807	0.233	0.427	-1.024	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	1288.637	266.303	1.294	0.427	3.316	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	1196.320	493.598	2.518	0.427	7.941	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1038.266	324.604	1.046	0.427	0.555	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	1340.127	409.980	1.561	0.427	3.244	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	1108.603	343.615	0.888	0.427	0.951	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	1025.121	205.908	0.747	0.427	0.749	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	1300.110	214.148	0.487	0.427	1.088	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	1153.298	353.031	1.776	0.427	5.966	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	1975.507	500.159	0.861	0.427	0.705	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	2088.963	490.398	0.763	0.427	0.572	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	2204.931	644.124	1.776	0.427	4.399	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	2030.298	618.559	0.802	0.427	0.381	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	2133.702	513.785	0.586	0.427	-0.610	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	2357.619	690.157	1.277	0.427	1.308	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	2081.458	666.942	0.799	0.427	0.883	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	2179.365	588.111	0.869	0.427	0.657	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	2402.536	802.526	1.808	0.427	4.689	0.833

APPENDIX C: DESCRIPTIVE STATISTICS FOR STERNBERG TASK RESPONSE TIMES (INTERLACED TASKS)

Table 15. *Descriptive Statistics for Interlaced Task-Sternberg RT Data (Spatially Unrouped Stimuli).*

Condition	*N*	*M*	*SD*	Skewness Statistic	Skewness *SE*	Kurtosis Statistic	Kurtosis *SE*
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	1285.685	488.307	0.595	0.427	-0.394	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	1539.913	510.630	1.490	0.427	2.566	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	1447.413	528.611	0.851	0.427	0.442	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1211.592	379.910	0.432	0.427	-0.772	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	1639.523	530.533	1.102	0.427	1.303	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	1434.687	463.191	0.195	0.427	-0.576	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	1329.497	530.369	1.023	0.427	1.418	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	1595.521	487.732	0.384	0.427	-0.722	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	1579.304	706.293	1.641	0.427	3.364	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	1700.258	582.506	1.097	0.427	0.519	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	2146.680	586.482	0.608	0.427	-0.486	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	2129.156	770.265	0.681	0.427	-0.476	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	1665.323	666.547	1.558	0.427	2.730	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	2329.611	803.017	0.938	0.427	1.174	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	2083.726	842.161	1.070	0.427	0.444	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	1723.569	559.406	0.595	0.427	-0.662	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	2242.121	616.552	0.224	0.427	-0.881	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	2168.626	757.644	1.278	0.427	2.132	0.833

Table 16. *Descriptive Statistics for Interlaced Task-Sternberg RT Data (Spatially Grouped Stimuli).*

Condition	*N*	*M*	*SD*	Skewness Statistic	Skewness *SE*	Kurtosis Statistic	Kurtosis *SE*
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	1097.518	335.268	1.554	0.427	2.515	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	1437.216	337.102	0.221	0.427	-0.942	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	1170.860	310.830	0.671	0.427	0.449	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1051.758	325.189	1.459	0.427	2.023	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	1433.492	319.617	0.607	0.427	0.207	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	1179.323	361.399	0.834	0.427	0.541	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	1149.496	406.223	2.603	0.427	9.329	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	1485.699	408.384	1.788	0.427	3.976	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	1218.786	302.960	0.949	0.427	2.258	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	2073.019	592.045	0.636	0.427	0.047	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	2188.841	591.563	0.449	0.427	-0.382	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	2316.724	627.666	0.515	0.427	-0.508	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	2259.030	722.311	0.143	0.427	-1.317	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	2460.178	776.572	0.682	0.427	-0.054	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	2611.997	733.101	0.147	0.427	-0.114	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	2059.372	633.191	0.570	0.427	-0.422	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	2410.711	658.213	0.183	0.427	-0.708	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	2466.635	664.428	0.477	0.427	0.413	0.833

APPENDIX D: DESCRIPTIVE STATISTICS FOR WM LOADING TASK DATA (SEPARATED TASKS)

Table 17. *Descriptive Statistics for Separated Task-WM Task Data (Spatially Grouped Stimuli).*

				Skewness		**Kurtosis**	
Condition	**N**	***M***	***SD***	**Statistic**	***SE***	**Statistic**	***SE***
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	0.893	0.202	-2.175	0.427	4.577	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	0.900	0.188	-1.747	0.427	1.868	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	0.913	0.194	-2.619	0.427	6.784	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	0.933	0.132	-2.588	0.427	8.274	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	0.900	0.164	-1.608	0.427	1.905	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	0.900	0.227	-2.487	0.427	5.310	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1.000	0.000	.	.	.	.
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	1.000	0.000	.	.	.	.
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	1.000	0.000	.	.	.	.
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	1.000	0.000	.	.	.	.
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	1.000	0.000	.	.	.	.
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	1.000	0.000	.	.	.	.
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	0.860	0.183	-1.237	0.427	0.798	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	0.853	0.148	-0.480	0.427	-0.972	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	0.853	0.189	-1.634	0.427	3.517	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	0.847	0.194	-0.989	0.427	-0.152	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	0.827	0.136	-0.170	0.427	-0.715	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	0.857	0.189	-1.692	0.427	3.665	0.833

Table 18. *Descriptive Statistics for Separated Task-WM Task Data (Spatially Ungrouped Stimuli).*

Condition	N	*M*	*SD*	Skewness Statistic	*SE*	Kurtosis Statistic	*SE*
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	0.938	0.137	-2.817	0.427	8.405	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	0.953	0.122	-2.650	0.427	5.679	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	0.950	0.110	-2.516	0.427	5.799	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	0.954	0.096	-2.389	0.427	5.738	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	0.929	0.117	-1.748	0.427	2.437	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	0.967	0.069	-1.958	0.427	2.339	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	1.000	0.000	.	.	.	.
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	0.993	0.037	-5.477	0.427	30.000	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	0.993	0.037	-5.477	0.427	30.000	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	1.000	0.000	.	.	.	.
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	1.000	0.000	.	.	.	.
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	0.987	0.051	-3.660	0.427	12.207	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	0.833	0.211	-0.924	0.427	-0.472	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	0.887	0.136	-0.805	0.427	-0.402	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	0.873	0.144	-0.692	0.427	-0.699	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	0.820	0.177	-0.525	0.427	-0.736	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	0.847	0.136	-0.323	0.427	-0.722	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	0.867	0.121	-0.294	0.427	-0.550	0.833

APPENDIX E: DESCRIPTIVE STATISTICS FOR WM LOADING TASK DATA (INTERLACED TASKS)

Table 19. *Descriptive Statistics for Interlaced Task-WM Task Data (Spatially Grouped Stimuli).*

				Skewness		Kurtosis	
Condition	**N**	***M***	***SD***	**Statistic**	***SE***	**Statistic**	***SE***
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	0.780	0.289	-1.127	0.427	-0.127	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	0.724	0.285	-0.877	0.427	0.042	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	0.777	0.269	-1.311	0.427	1.256	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	0.789	0.247	-1.135	0.427	0.627	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	0.773	0.286	-1.404	0.427	1.673	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	0.690	0.316	-0.741	0.427	-0.365	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	0.953	0.125	-2.509	0.427	4.849	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	0.973	0.069	-2.273	0.427	3.386	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	0.873	0.178	-1.140	0.427	0.167	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	0.893	0.202	-2.175	0.427	4.577	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	0.900	0.155	-1.182	0.427	-0.207	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	0.947	0.148	-2.806	0.427	7.190	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	0.667	0.259	-0.268	0.427	-0.201	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	0.693	0.187	-0.032	0.427	-0.773	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	0.713	0.201	-0.086	0.427	-0.991	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	0.707	0.221	-0.582	0.427	0.136	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	0.767	0.204	-1.316	0.427	2.338	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	0.753	0.194	-0.220	0.427	-0.914	0.833

Table 20. *Descriptive Statistics for Interlaced Task-WM Task Data (Spatially Grouped Stimuli).*

Condition	N	*M*	*SD*	Skewness Statistic	*SE*	Kurtosis Statistic	*SE*
Set Size_3/WM loading_Visual/Sternberg Task_Visual	30	0.862	0.217	-1.726	0.427	2.389	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Auditory	30	0.821	0.265	-1.469	0.427	1.027	0.833
Set Size_3/WM loading_Visual/Sternberg Task_Tactile	30	0.840	0.200	-1.103	0.427	0.161	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Visual	30	0.832	0.208	-1.150	0.427	0.195	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Auditory	30	0.795	0.239	-1.780	0.427	3.887	0.833
Set Size_6/WM loading_Visual/Sternberg Task_Tactile	30	0.861	0.180	-1.237	0.427	0.953	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Visual	30	0.960	0.097	-2.499	0.427	6.057	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Auditory	30	0.933	0.121	-1.693	0.427	1.958	0.833
Set Size_3/WM loading_Auditory/Sternberg Task_Tactile	30	0.927	0.153	-2.217	0.427	4.517	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Visual	30	0.880	0.207	-1.899	0.427	3.298	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Auditory	30	0.867	0.212	-1.291	0.427	0.192	0.833
Set Size_6/WM loading_Auditory/Sternberg Task_Tactile	30	0.833	0.211	-0.924	0.427	-0.472	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Visual	30	0.840	0.133	-0.242	0.427	-0.634	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Auditory	30	0.727	0.207	-0.384	0.427	-0.038	0.833
Set Size_3/WM loading_Tactile/Sternberg Task_Tactile	30	0.820	0.169	-0.198	0.427	-1.585	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Visual	30	0.680	0.233	-0.587	0.427	1.063	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Auditory	30	0.787	0.189	-0.124	0.427	-1.388	0.833
Set Size_6/WM loading_Tactile/Sternberg Task_Tactile	30	0.727	0.238	-0.406	0.427	-0.864	0.833

APPENDIX F: CORRELATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
GESTALT	--	.17	.15	-.06	.09	.24	-.08	-.06	.01	-.15	.01	-.12	.09	-.08	.11	-.01	.05	-.10	.04	-.02	-.07	-.19	-.07	-.11
PPR_FLD		--	.18	.28	-.05	.08	-.30	-.43	-.21	-.36	-.27	-.36	-.25	-.34	-.20	-.16	-.29	-.25	-.23	-.35	-.11	-.14	-.30	-.31
PIC_MEM			--	.06	-.12	.10	-.06	-.14	.01	.06	.05	-.10	-.07	-.10	-.07	-.14	-.05	-.06	-.02	.08	.07	.08	.06	.00
VIS_SPAN				--	.01	-.15	-.23	-.36	-.15	-.29	-.18	-.25	-.26	-.26	-.14	-.30	-.25	-.13	-.11	-.04	-.12	-.27	-.12	-.18
AUD_SPAN					–	.29	-.09	.17	-.16	-.01	-.07	-.10	-.02	-.08	.14	-.02	.10	-.10	-.05	-.02	-.14	-.02	-.12	-.01
TAC_SPAN						--	.00	.06	-.14	-.03	.10	-.08	.00	.10	-.03	.02	.03	.02	.12	.21	.02	.07	.01	.09
SMEAN(R3_B_VV)							–	.60	.69	.50	.76	.48	.68	.54	.58	.35	.53	.32	.81	.54	.62	.42	.70	.66
SMEAN(V4)								--	.62	.62	.57	.70	.47	.61	.54	.58	.58	.51	.44	.52	.33	.56	.45	.59
SMEAN(R3_B_AV)									–	.75	.64	.61	.58	.57	.64	.49	.56	.42	.50	.57	.55	.58	.61	.69
SMEAN(V6)										--	.56	.58	.39	.55	.47	.50	.49	.40	.36	.56	.43	.64	.56	.68
SMEAN(R3_B_TV)											–	.43	.49	.49	.49	.41	.60	.33	.57	.44	.50	.37	.77	.65
SMEAN(V8)												--	.39	.53	.47	.45	.51	.56	.38	.47	.36	.54	.44	.57
SMEAN(R3_B_VA)													–	.63	.70	.43	.64	.47	.68	.52	.47	.28	.48	.41
SMEAN(V10)														--	.50	.61	.42	.67	.39	.60	.19	.30	.37	.53
SMEAN(R3_B_AA)															--	.45	.74	.41	.56	.45	.39	.41	.54	.41
SMEAN(V12)																--	.47	.52	.28	.37	.22	.42	.25	.48
SMEAN(R3_B_TA)																	--	.52	.56	.50	.49	.41	.65	.48
SMEAN(V14)																		--	.30	.45	.20	.26	.36	.51
SMEAN(R3_B_VT)																			--	.65	.71	.37	.72	.53
SMEAN(V16)																				--	.47	.48	.54	.61
SMEAN(R3_B_AT)																					--	.55	.69	.45
SMEAN(V18)																						–	.50	.48
SMEAN(R3_B_TT)																							--	.62
SMEAN(V20)																								–

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
GESTALT	–	.17	.15	-.06	.09	.24	-.06	-.06	.08	-.01	.01	-.26	.18	-.08	.03	.00	.05	-.08	.16	.03	-.03	-.07	.17	.15
PPR_FLD		–	.18	.28	-.05	.08	-.27	-.23	-.37	-.20	-.28	-.19	-.29	-.34	-.09	-.17	-.37	-.41	-.27	-.33	-.14	-.28	-.26	-.16
PIC_MEM			--	.06	-.12	.10	-.05	-.09	-.03	-.01	.05	-.22	-.01	-.11	.04	-.05	-.12	-.04	-.01	-.01	-.09	-.14	-.03	.14
VIS_SPAN				–	.01	-.15	-.11	-.18	-.30	-.19	-.01	-.18	-.23	-.26	-.20	-.20	-.21	-.26	-.17	-.23	-.23	-.29	-.16	-.14
AUD_SPAN					--	.29	-.19	-.15	-.02	-.21	.02	.01	-.03	-.12	-.19	-.30	-.03	-.06	-.02	-.08	-.29	.04	-.05	.08
TAC_SPAN						–	-.16	-.08	.00	-.08	.00	.02	-.06	-.11	-.07	-.09	-.13	-.13	-.10	-.05	-.13	-.13	-.08	.11
SMEAN(R6_B_VV)							--	.69	.54	.40	.66	.53	.62	.68	.58	.43	.47	.59	.50	.56	.43	.45	.41	.24
SMEAN(V22)								–	.40	.62	.50	.68	.48	.72	.41	.46	.37	.69	.43	.67	.32	.51	.47	.43
SMEAN(R6_B_AV)									--	.25	.58	.25	.45	.35	.50	.28	.45	.38	.35	.27	.53	.40	.28	.17
SMEAN(V24)										–	.26	.55	.25	.45	.45	.52	.23	.62	.23	.57	.23	.54	.29	.55
SMEAN(R6_B_TV)											--	.45	.47	.46	.41	.21	.53	.48	.49	.38	.48	.38	.41	.31
SMEAN(V26)												–	.21	.48	.20	.37	.22	.64	.15	.42	.21	.53	.21	.44
SMEAN(R6_B_VA)													--	.62	.61	.27	.78	.47	.82	.50	.51	.42	.74	.30
SMEAN(V28)														--	.57	.62	.56	.76	.58	.72	.42	.48	.53	.39
SMEAN(R6_B_AA)															–	.59	.52	.46	.61	.45	.65	.53	.55	.29
SMEAN(V30)																--	.32	.67	.29	.58	.45	.50	.36	.48
SMEAN(R6_B_TA)																	–	.56	.72	.48	.55	.49	.69	.33
SMEAN(V32)																		--	.47	.70	.39	.63	.54	.60
SMEAN(R6_B_VT)																			–	.61	.64	.51	.81	.39
SMEAN(V34)																				--	.44	.58	.56	.64
SMEAN(R6_B_AT)																					–	.55	.55	.26
SMEAN(V36)																						--	.60	.46
SMEAN(R6_B_TT)																							–	.48
SMEAN(V38)																								--

Table 21. *Sternberg task RT correlations with pre-tests.*

	Gestalt	PPR_FLD	PIC_MEM	VIS_SPAN	AUD_SPAN	TAC_SPAN
GESTALT	–	.17	.15	-.06	.09	.24
PPR_FLD	.17	–	.18	.28 *	-.05	.08
PIC_MEM	.15	.18	–	.06	-.12	.10
VIS_SPAN	-.06	.28 *	.06	–	.01	-.15
AUD_SPAN	.09	-.05	-.12	.01	–	.29 *
TAC_SPAN	.24	.08	.10	-.15	.29 *	–
SMEAN(R3_B_VV)	-.08	-.30 *	-.06	-.23	-.09	.00
SMEAN(V4)	-.06	-.43 *	-.14	-.36 *	.17	.06
SMEAN(R3_B_AV)	.01	-.21	.01	-.15	-.16	-.14
SMEAN(V6)	-.15	-.36 *	.06	-.29 *	-.01	-.03
SMEAN(R3_B_TV)	.01	-.27 *	.05	-.18	-.07	.10
SMEAN(V8)	-.12	-.36 *	-.10	-.25	-.10	-.08
SMEAN(R3_B_VA)	.09	-.25	-.07	-.26 *	-.02	.00
SMEAN(V10)	-.08	-.34 *	-.10	-.26 *	-.08	.10
SMEAN(R3_B_AA)	.11	-.20	-.07	-.14	.14	-.03
SMEAN(V12)	-.01	-.16	-.14	-.30 *	-.02	.02
SMEAN(R3_B_TA)	.05	-.29 *	-.05	-.25	.10	.03
SMEAN(V14)	-.10	-.25	-.06	-.13	-.10	.02
SMEAN(R3_B_VT)	.04	-.23	-.02	-.11	-.05	.12
SMEAN(V16)	-.02	-.35 *	.08	-.04	-.02	.21
SMEAN(R3_B_AT)	-.07	-.11	.07	-.12	-.14	.02
SMEAN(V18)	-.19	-.14	.08	-.27 *	-.02	.07
SMEAN(R3_B_TT)	-.07	-.30 *	.06	-.12	-.12	.01
SMEAN(V20)	-.11	-.31 *	.00	-.18	-.01	.09
SMEAN(R6_B_VV)	-.06	-.27 *	-.05	-.11	-.19	-.16
SMEAN(V22)	-.06	-.23	-.09	-.18	-.15	-.08
SMEAN(R6_B_AV)	.08	-.37 *	-.03	-.30 *	-.02	.00
SMEAN(V24)	-.01	-.20	-.01	-.19	-.21	-.08
SMEAN(R6_B_TV)	.01	-.28 *	.05	-.01	.02	.00
SMEAN(V26)	-.26 *	-.19	-.22	-.18	.01	.02
SMEAN(R6_B_VA)	.18	-.29 *	-.01	-.23	-.03	-.06
SMEAN(V28)	-.08	-.34 *	-.11	-.26 *	-.12	-.11
SMEAN(R6_B_AA)	.03	-.09	.04	-.20	-.19	-.07
SMEAN(V30)	.00	-.17	-.05	-.20	-.30 *	-.09
SMEAN(R6_B_TA)	.05	-.37 *	-.12	-.21	-.03	-.13
SMEAN(V32)	-.08	-.41 *	-.04	-.26 *	-.06	-.13
SMEAN(R6_B_VT)	.16	-.27 *	-.01	-.17	-.02	-.10
SMEAN(V34)	.03	-.33 *	-.01	-.23	-.08	-.05
SMEAN(R6_B_AT)	-.03	-.14	-.09	-.23	-.29 *	-.13
SMEAN(V36)	-.07	-.28 *	-.14	-.29 *	.04	-.13
SMEAN(R6_B_TT)	.17	-.26 *	-.03	-.16	-.05	-.08
SMEAN(V38)	.15	-.16	.14	-.14	.08	.11

* denotes significance $p < .05$

Table 22. *WM task correlations with pre-tests.*

	Gestalt	PPR_FLD	PIC_MEM	VIS_SPAN	AUD_SPAN	TAC_SPAN
GESTALT	--	.17	.15	-.06	.09	.09
PPR_FLD	.17	--	.18	.28 *	-.05	.11
PIC_MEM	.15	.18	--	.07	-.12	.20
VIS_SPAN	-.06	.28 *	.07	--	.00	.13
AUD_SPAN	.09	-.05	-.12	.00	--	.16
TAC_SPAN	.09	.11	.20	.13	.16	–
SMEAN(R3_B_VV)	.07	.15	.05	.38 *	.28 *	-.01
SMEAN(V4)	.07	-.08	-.08	.17	.24	-.01
SMEAN(R3_B_AV)	.02	.01	-.01	.34 *	.11	-.09
SMEAN(V6)	.29 *	.19	-.08	.19	.11	.13
SMEAN(R3_B_TV)	.16	.39 *	.17	.13	.03	-.07
SMEAN(V8)	.10	.10	-.12	.11	-.01	.09
SMEAN(R3_B_VA)	.01	.06	-.15	.25 *	.09	-.14
SMEAN(V10)	.08	-.07	-.21	.25	.06	-.02
SMEAN(R3_B_AA)	.13	.04	-.07	.11	.00	-.13
SMEAN(V12)	.02	.29 *	-.07	.33 *	.08	-.17
SMEAN(R3_B_TA)	.26 *	.26 *	.03	.12	.22	-.11
SMEAN(V14)	.26 *	.25	.09	.14	.09	.20
SMEAN(R3_B_VT)	a	a	a	a	a	a
SMEAN(V16)	-.13	.04	-.04	.15	.10	.21
SMEAN(R3_B_AT)	-.17	.19	.04	.00	.10	-.03
SMEAN(V18)	.06	.29 *	.24	.08	.26 *	.50 *
SMEAN(R3_B_TT)	-.06	.14	-.02	-.11	.34 *	.14
SMEAN(V20)	.20	.33 *	.16	.05	.30 *	.42 *
SMEAN(R6_B_VV)	a	a	a	a	a	a
SMEAN(V22)	a	a	a	a	a	a
SMEAN(R6_B_AV)	.01	.29 *	.06	.05	.07	.13
SMEAN(V24)	.05	.51 *	.25	.20	.11	.25
SMEAN(R6_B_TV)	.02	.18	.07	.03	.02	.17
SMEAN(V26)	.18	.20	.15	.01	.20	.11
SMEAN(R6_B_VA)	.06	.23	.10	-.10	.23	.02
SMEAN(V28)	.08	.33 *	.10	.12	.11	.27 *
SMEAN(R6_B_AA)	.06	.17	-.04	.49 *	.05	.16
SMEAN(V30)	.04	.22	.09	.18	.17	.32 *
SMEAN(R6_B_TA)	-.07	.10	-.13	.13	.04	-.25
SMEAN(V32)	-.20	.15	-.02	.12	.02	.24
SMEAN(R6_B_VT)	.02	.28 *	.01	.06	.14	.19
SMEAN(V34)	.05	.29 *	.04	.14	.24	.08
SMEAN(R6_B_AT)	.03	.20	-.11	.16	.19	.09
SMEAN(V36)	-.12	-.12	.19	-.06	-.12	.13
SMEAN(R6_B_TT)	.05	.26 *	.07	.17	.07	.22
SMEAN(V38)	-.04	.46 *	.17	.13	.03	.02

* denotes significance $p < .05$

APPENDIX G: INFORMED CONSENT

Informed Consent Statement

Please read this consent document carefully before you decide to participate in this study.

You must be 18 years of age or older to participate.

Project title: MULTIMODAL ENCODING AND UNIMODAL CUED RETRIEVAL DURING CONCURRENT TASKS: EXPANDING THE STERNBERG RECALL TASK

Purpose of the research study: The purpose of this study is to examine the effects of unisensory retrieval cues for multisensory memories during simultaneous tasks.

What you will be asked to do in the study: You will be asked to complete several demographics questionnaires. The experimenter will then ask to measure around your abdomen in order to custom-fit the tactile display. You will then be asked to change privately into a laboratory T-shirt to standardize the material between the tactile display and the skin. The experimenter will then conduct several measures of your verbal, visual, and tactile memory spans. There will be another short-term memory test and then you will begin to memorize short sequences of simultaneous visual, auditory, and tactile information. You will then be asked to recall this information while simultaneously remembering additional visual/verbal material, or while performing simple mathematical operations.

Time required: Approximately 2 hrs.

Risks: The anticipated risks in this study are similar to computer and cellular telephone use and are therefore deemed minimal risks.

Benefits/Compensation: The compensation for participation is extra-credit for undergraduate UCF courses (as allowed by the course instructor). Credit will be assigned via Sona Systems at the rate of one extra-credit point for every half hour of participation. Any additional portion of a half hour will be rounded up as per Sona Systems guidelines. A potential benefit of this study is a contribution to the understanding of memory aspects associated with new multisensory displays.

Confidentiality: Your identity will be kept confidential. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

Voluntary participation: Your participation in this study is voluntary. There is no penalty for not participating. You have the right to withdraw from the study at any time without penalty.

Whom to contact if you have questions about the study: You may contact Peter Terrence, (Graduate Student, Psychology Department, College of Sciences, 4000 Central Florida Blvd, Orlando, FL 32816) at (407) 882-0301, or by e-mail at pterrence@gmail.com. You may also contact Dr. Richard Gilson, Faculty Supervisor, Psychology Department at (407) 823-2755 or by email at gilson@mail.ucf.edu.

Whom to contact about your rights in the study: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (IRB). For information about participants' rights please contact: Institutional Review Board Office, University of

Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246. The telephone numbers are (407) 882-2276 and (407) 823-2901. The office is open from 8:00 am to 5:00 pm Monday through Friday except on UCF official holidays.

___ I have read the procedure described above.

___ I voluntarily agree to participate in the procedure.

____

Print Participant Name

____

Participant Signature Date

____

Principle Investigator Signature Date

APPENDIX H: DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire

Participant # _______ Date ___________

Age _________ Major ____________________________________ Gender : M / F

1. What is the <u>highest</u> level of education you have had?

Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*<u>Circle all that apply</u>*)

Grade School	Jr. High	High School
Technical School	College	Did Not Use

3. Where do you currently use a computer? (*<u>Circle all that apply</u>*)

Home Work Library Other________ Do Not Use

4. Which of the following best describes your expertise with computer? (*<u>Check only one</u>*)

_____ Novice

_____ Good with one type of software package (such as word processing or slides)

_____ Good with several software packages

_____ Can program in one language and use several software packages

_____ Can program in several languages and use several software packages

5. Are you in your usual state of health physically? YES NO

If NO, please explain: ____

____

____

____

6. How many hours of sleep did you get last night? ______ hours

7. Do you have normal color vision? YES NO

8. Do you have any hearing loss, visual impairment (other than color blindness), loss of skin sensation, or motor difficulty that may affect this experiment? Y / N

If YES, please explain: ____

____

____

____

APPENDIX I: DEBRIEFING FORM

Debriefing Form

The purpose of this study is to determine the effects of multiple tasks on memory for multimodal stimuli. If you are interested in learning more about this avenue of research, the following resources might be helpful:

Baddeley, A. D. (2001). “Is Working Memory Still Working?” *American Psychologist, 56*, 849–864.

Wickens, C. D., Sandry, D., & Vidulick, M. (1983). Compatibility and resource competition between modalities of input, output, and central processing. *Human Factors, 25*, 227-248.

If you have further questions regarding your participation in this experiment, please contact Peter Terrence at (407) 882-0301 or pterrence@gmail.com, or you can reach Dr. Gilson at (407) 823-2755.

APPENDIX J: STIMULUS EXAMPLES

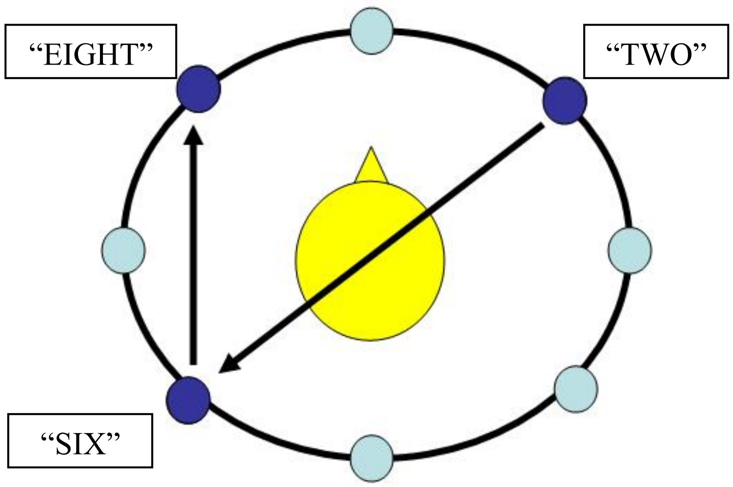

Figure 32. Ungrouped, three-item Sternberg task stimulus for encoding.

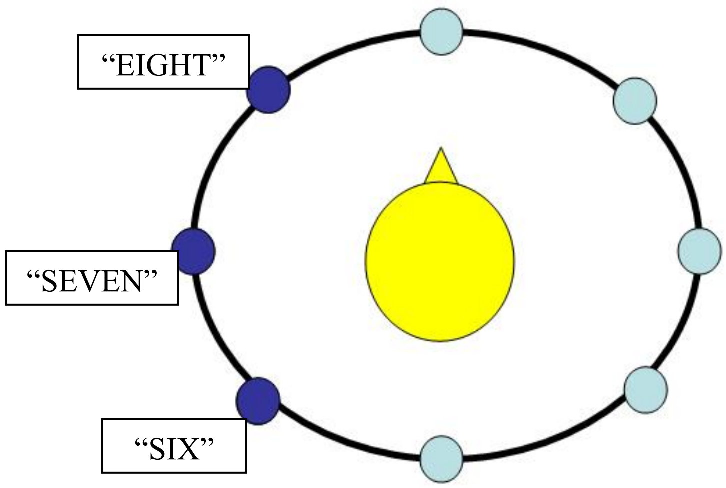

Figure 33. Grouped, three-item Sternberg task stimulus for encoding.

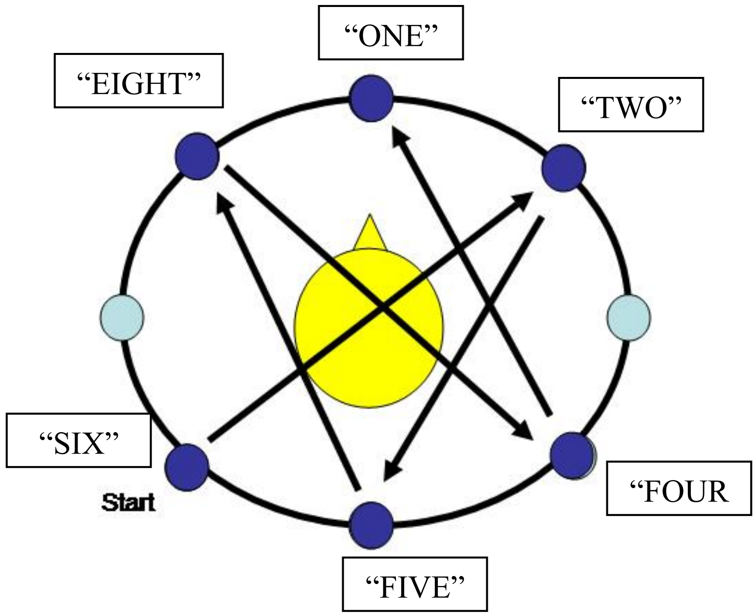

Figure 34. Ungrouped, six-item Sternberg task stimulus for encoding.

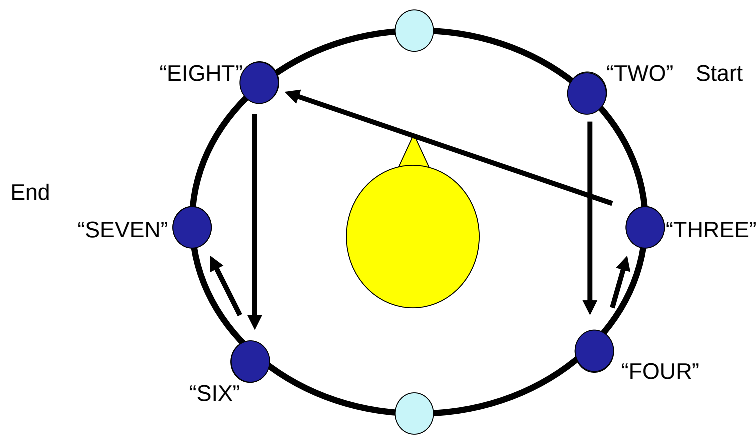

Figure 35. Grouped, six-item Sternberg task stimulus for encoding.

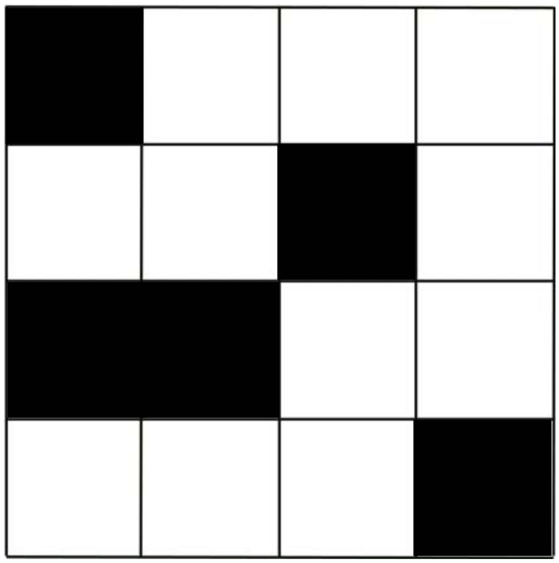

Figure 36. Example of visual stimulus for VSSP loading. Note: This figure shows what had to be maintained in memory. Each black square element appeared individually and then disappeared before the next one became visible.

LIST OF REFERENCES

Allen, R. J., Baddeley, A. D., Hitch, G. J. (2006). Is the binding of visual features in Working Memory resource-demanding? *Journal of Experimental Psychology: General, 135*(2), 298-313.

Atkinson, R. C. & Shiffrin. (1968). Human memory: A proposed system and its control processes. In K. W. Spence, and J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in Research and Theory* (Vol. 2, pp. 89-105). New York: Academic Press.

Baddeley, A. D. (2001). "Is Working Memory still working?" *American Psychologist, 56*, 849–864.

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Creation Date: 4/6/2008 3:33 PM
Change Number: 16
Last Saved On: 4/12/2008 4:52 PM
Last Saved By: Peter Terrence
Total Editing Time: 624 Minutes
Last Printed On: 4/12/2008 4:53 PM
As of Last Complete Printing
Number of Pages: 161
Number of Words: 28,315 (approx.)
Number of Characters: 162,814 (approx.)