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UNIVERSITY OF ALBERTA

EXAMINING MEMORY FOR MOVEMENTS USING A DYNAMIC MEMORY TASK

BY

© **TINA E. GABRIELE**

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of **Doctor of Philosophy**.

Department of Physical Education and Sport Studies

Edmonton, Alberta
Spring, 1992

ISBN 0-315-73225-3

UNIVERSITY OF ALBERTA

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NAME OF AUTHOR: Tina Ellen Gabriele

TITLE OF THESIS: Examining Memory for Movements Using a Dynamic Memory Task

DEGREE: Doctor of Philosophy

YEAR THIS DEGREE GRANTED: SPRING 1992

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Abstract

Memory tasks are abundant in almost all acts of everyday cognition. Although a precise definition and the structural nature of memory have been left unresolved, numerous models of memory have evolved. Two such models, Atkinson and Shiffrin (1968) and Baddeley (1986), are described and contrasted in detail. Both models, originally designed to explain verbal phenomena, may also be applied to the motor modality. The field of motor memory rose to prominence in the early 1960's. Unfortunately, the one-item long experimental paradigm frustrated researchers because of a failure to contribute to an adequate theory of motor memory. A new approach for examining memory for movements, called the back memory paradigm, is utilized in the following experiments. The subject is presented movement items one at a time until a predetermined load has been achieved. Once the maximum load size is reached, a new item is presented and the subject is asked to recall the first movement item. The first movement item is removed from memory and the new item is coded and stored. The purpose of the first experiment is to investigate the effect of increasing load upon memory for multiple movements. Results indicate that the size of deviation from the correct spatial location increases with increasing load, both for correct and incorrect responses. As the memory trace weakens, subjects produce successively larger spatial location errors. The second experiment is designed to investigate the effect of a secondary task (articulatory suppression, counting backward, or repetitive tapping) on the primary back memory task. In addition to replicating the results of the first experiment, the second experiment shows that all the secondary tasks cause performance decrements, with the greatest overall interference associated with the counting backward condition. Results are discussed in relation to the predictions of the two memory models, and in particular, Baddeley's concept of Working Memory.

ACKNOWLEDGEMENTS

The fact that I am writing these acknowledgements can only mean one thing: I must be finished!! There are many people that made it possible for me to get to this stage of the writing and I would like to take this opportunity to thank them.

I would like to thank my advisor, Dr. R.B. Wilberg, for the many valuable lessons. Willy you ensured that I was continually challenged and I thank you for insisting that I meet those challenges. The seemingly endless seminars, discussions, and questions, provided me with an education for which I am truly grateful. Willy I guess I finally drank from "the trough".

I would also like to acknowledge the help and support of my examining committee. To Dr. R.B. Alderman for helping me to not lose sight of the "real world". To Dr. P. Gervais for bringing another perspective to my research. I would like to thank Dr. A. Dobbs whose insight and knowledge made an invaluable contribution to my understanding of this area. I would like to thank Dr. G. Fishburne for not only being an examiner and the committee chairperson but also for making a stressful situation enjoyable. Finally, I would like to extend my gratitude to my external examiner, Dr. D. Elliott for his worthwhile input to my thesis and for his endless support and friendship over the past few years.

My heartfelt thanks to my family; Mom, Dad, Paula, Nick, John, and Carla for being the ultimate in support. They have been there every step of the way with me. Their unconditional love and trust is irreplaceable. Thanks for being so wonderful!

I obtained an incredible amount of strength and drive from my very dear friend, Aaron. Good or bad, you were always willing to listen. Thank you for all the smiles, laughs, good times and tears. Your friendship is a precious gift that I will treasure always.

I have also been blessed with the friendship of one of the most sensitive and passionate individuals I have ever met. Sandy, thanks for helping me to reflect upon what truly is important in life. I cannot adequately express the value of our friendship.

My five years in Edmonton have been filled with great memories because of a number of friends. I would like to also say thanks to "The Girls": Annie, Carm, Leeser, Lucie, and MacChinn. You truly are friends.

Finally, I would like to thank "The Boys in the Lab". Jim, our special friendship is one in a million and I feel very fortunate to share it with you. To Cam, your friendship and unique sense of humour has added many a smile. Jay, you have become a friend who will always be welcome. To Andonis, the lab can be a difficult environment but we made it through as friends. I am very fortunate to have worked with such exceptional individuals.

Once again, to all the above, my deepest thanks for all you have done for me.

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Almost all acts of cognition require memory, or involve a memory component. Everyday examples of this involvement include: trying to recall an individual's phone number, giving an officer an accurate account of what occurred at the scene of an accident, attempting to ride a bicycle after 20 years, and repeating a favourite childhood story. In these instances, past experiences are used to assist the individual in producing the desired response (Tulving, 1985).

Memory is perceived and defined by a number of researchers in various ways. Underwood (1969) states that a memory is an organism's record of an event. Jacoby and Craik (1979) believe that a memory is a record of the amount and types of processing that occurred when an item was originally presented. Tulving (1983) differentiates between memory for events (episodic memory), and memory for meaning (semantic memory). Sherry and Schacter (1987) define memory as a function that allows one to acquire, retain, and retrieve many different kinds of information. Regardless of which definition of memory is employed, the recurring theme appears to be a reliance on some past event that enables the individual to produce an appropriate response.

The experimental study of memory began over a century ago. In 1885, Ebbinghaus studied the factors that governed the retention of very simple material. He repeated a list of nonsense syllables, of the form consonant-vowel-consonant (CVC), at a rate of 2.5 syllables per second until he could reproduce the list correctly. Each repetition of the list on the first day was found to save 12 seconds on relearning the next day. Further analysis indicated the forgetting rate to be a logarithmic relationship with the greatest amount of forgetting occurring in the first hour and levelling off after that time period. Although Ebbinghaus failed to draw any theoretical conclusions from his work, he did lay the groundwork for experimental examination of memory problems (Baddeley, 1976). After the advent of memory research, psychologists began to apply theoretical concepts to some of the memory phenomena.

Historically, the structural nature of memory has been debated between two predominant viewpoints. One view is that memory has properties indicative of both a short-term component (STM) and a long-term component (LTM) (e.g. Atkinson and Shiffrin, 1968; Baddeley, 1976; Brown, 1958; James, 1890; Murdock, 1974; Peterson and

Peterson, 1959; Postman, 1964). The other theme is that memory is comprised of only one system (e.g. Gruneberg, 1970; Melton, 1963; Wickelgren, 1973).

The differentiation between "primary" memory and "secondary" memory made by James (1890) is indicative of the dichotomous view. The primary memory system is responsible for rehearsing items that have occurred in the immediate past (i.e. items are still in consciousness) and a lack of rehearsal results in items being lost forever. The secondary memory system on the other hand, is used to recall objects that are absent from consciousness but not lost from memory.

The unitary view of memory was put forth by Melton (1963) who failed to show differences between the phenomena of long-term memory (LTM) and short-term memory (STM). He believed that all memory phenomena, whether long-term or short-term in nature, could be explained by interference theory and therefore argued for one memory system with one set of underlying principles.

The question of whether two separate memory systems exist, or only a single system that functions at two different levels, is still unresolved. The consensus however, appears to be in favour of the dichotomous view that memory consists of a short-term component and a long-term component (Baddeley, 1986). Based on the notion that memory is separated into two systems, a number of theoretical models have been developed that attempt to conceptualize the structure of memory. The focus of this paper will rest upon two of the more prominent memory models related to information processing, namely the Atkinson and Shiffrin (1968) memory model and Baddeley's (1986) Working Memory Model.

MEMORY MODELS

Atkinson and Shiffrin (1968) contributed one of the most important and influential information processing models of memory structure (Baddeley, 1976; Magill, 1989). In the Atkinson-Shiffrin model (see diagram below), information from the environment enters the sensory registers where it is processed in parallel and resides for a very short time before decaying. Selected inputs from the sensory registers are received in the short-term store (STS). Activation of relevant information occurs simultaneously in the long-term store (LTS) and this additional information is transferred into the STS. The compilation of information in the STS, from both the sensory registers and LTS, allows decision making and problem solving to occur and, hence, the STS operates as the control centre of memory. The STS plays a vital role in this model of memory.

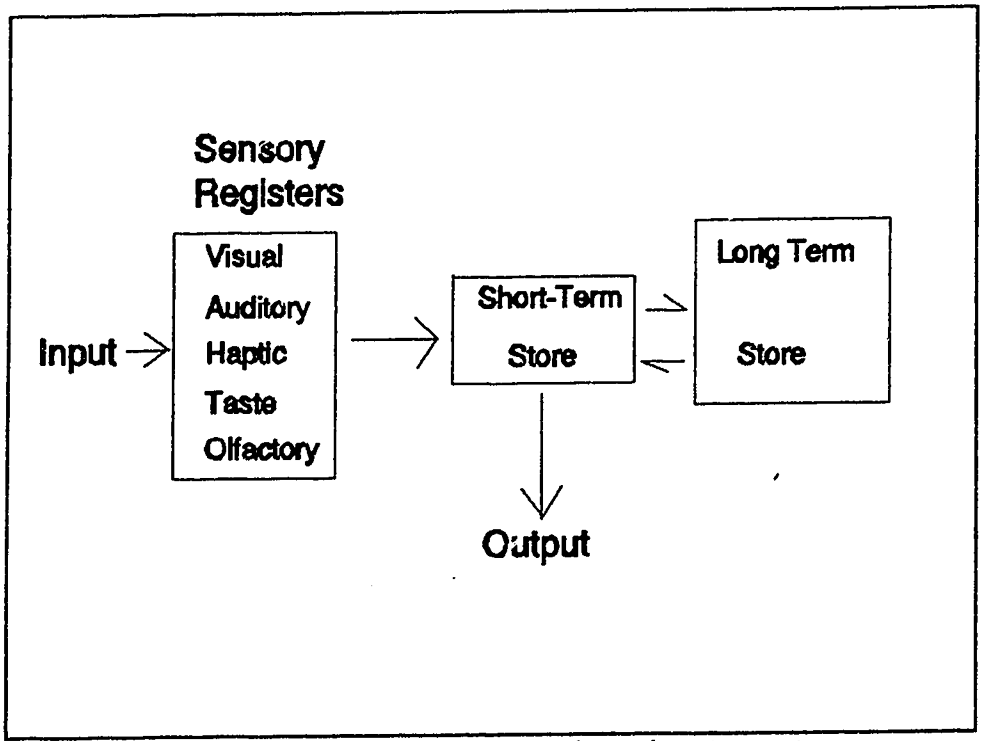

Figure 1. The Atkinson and Shiffrin (1968) Memory Model

The Atkinson-Shiffrin model emphasizes that memory must be considered in terms of both <u>structure</u> and <u>control</u> processes. The main structure of the model is the STS and its features remain fixed regardless of the task.

The STS is responsible for both the storage of information and the operation of control processes. Atkinson and Shiffrin assumed the STS to be capable of using a number of control processes and strategies, but they primarily studied the process of rote verbal rehearsal. The more frequently an item was rehearsed, the more likely it would be remembered later. The STS is considered to be the working memory of the Atkinson-Shiffrin model.

A logical comparison to the Atkinson-Shiffrin STS is Baddeley's (1986) concept of working memory (WM). Baddeley (1986) proposes a tripartite system of STM comprised of a supervisory controlling system, the central executive, and two "slave systems", the articulatory loop and the visuo-spatial sketch pad (see diagram below). (The model was originally conceptualized in 1974 by Baddeley and Hitch). The central executive (CE) possesses attentional capacities and is responsible for selecting and operating various control processes. It is modality free and acts as a link between a number of modality dependent peripheral systems (Baddeley, 1986). The slave systems are responsible for the processing and storage of information. Baddeley likens the articulatory loop to a tape loop of limited duration that stores phonological information with an articulatory control process (i.e. based on the speech production system). The visuo-spatial sketch pad processes and stores visualizable messages that rely on spatial rather than visual coding. Both slave systems are active stores in which information can be maintained by rehearsal (Baddeley, 1986).

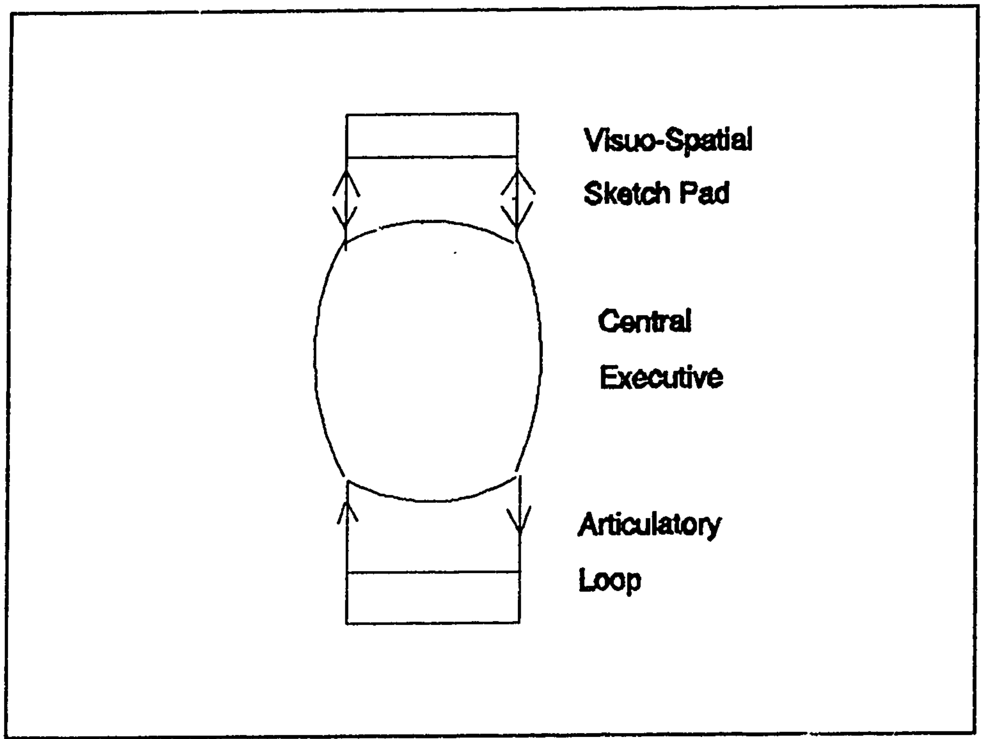

Figure 2. Baddeley's (1986) simplified representation of Working Memory

The Baddeley and Atkinson-Shiffrin memory models differ in a number of ways. First, the type of coding that occurs within the STS and WM are fundamentally different. The STS receives information from the sensory registers and encodes the incoming information either in an auditory, verbal, or linguistic form. All information, regardless of source, is transformed to a phonological code in the STS of the Atkinson-Shiffrin model.

Baddeley, on the other hand, does not rely totally on one type of code. In the articulatory loop, information is phonologically encoded either directly by auditory presentation or indirectly through subvocal articulation. Information in WM can also be encoded based on spatial properties in the visuo-spatial sketch pad. Baddeley believes the processing of visualizable messages to be based on a spatial rather than visual code because visuo-spatial tasks are disrupted by a secondary spatial task that is free from visual input. The WM model relies on a phonological code in the articulatory loop and a spatial code in the sketch pad.

The second area of difference between the two memory models deals with the nature of the limited capacity of the system. The STS contains a rehearsal buffer that possesses a maximum size. Each new item entering the STS can enter the buffer through the process of rehearsal. The buffer can be loaded to some maximum size after which older (earlier) items are replaced by incoming newer (later) items. The buffer is purported to have a maximum size of five to eight items. Further, information stored in the buffer may decay and be completely lost after 30 seconds, if not rehearsed. The STS, therefore, is limited in capacity by the structure of the system.

WM, on the other hand, is not limited by structure solely. The central executive possesses a limited amount of processing capacity, very little of which is devoted to the short-term storage of information. The storage demands are mainly off-loaded on to the slave systems. The articulatory loop acts like a tape loop of limited duration. In other words, the loop is limited by time but not by the amount of information or by the number of events. The other slave system, the visuo-spatial sketch pad, is not as well researched as the articulatory loop. Baddeley (1986) believes the sketch pad to be an active system that maintains information by rehearsal.

WM is fundamentally different from the STS in relation to limited capacity because WM is limited by control processes whereas the STS is limited by structure. The short-term characteristics of the central executive are attributable to its limited capacity for doing several types of operations at the same time. On the other hand, the limitation of the slave systems is connected to the durability of the information they contain. The STS is limited by the size of storage available while WM is limited by the amount of controlled processing that can occur at any one time.

Another capacity related difference between the two models is the nature of memory loss, or forgetting. Failure to remember information can occur in both the STS and WM if rehearsal does not occur. However, forgetting may also occur in both models if the memory system operates above maximal levels. The Atkinson-Shiffrin model predicts that once the STS buffer is operating at maximum capacity (i.e. maximally filled) few resources remain to perform other processes such as coding and/or long-term search. When these other processes are simultaneously required, a trade-off occurs. The size of the buffer is reduced to accommodate the necessary processes for task completion, leading to forgetting of some of the information that was originally present in the buffer. The result is that those portions of the original information that can no longer be rehearsed, decay and may become completely lost.

WM however, predicts that two tasks can occur simultaneously if they do not require the use of the same control processes, even if one is operating at or near maximum. The performance of the other cognitive task will be impaired, but the possibility still exists for completion of the primary task but at a lower quality. The central executive performs the scheduling and time sharing operations necessary when task demands require the performance of more than one task. Baddeley (1986) reports that subjects are able to load the articulatory loop to maximum with a memory span task while simultaneously performing an imagery task. Performance of both tasks is poorer than when no load is placed upon the loop but completion of the tasks is still possible.

According to the Atkinson-Shiffrin model, performance of an imagery task would not be possible unless the size of the memory span was affected as well. In other words, these two tasks could be performed concurrently only if a trade-off between capacity (span) and processing (imagery) occurred. Significant decrements in the memory span task would have to result in order for the imagery task to be completed. This trade-off is not found in Baddeley's experiments.

Finally, the WM model predicts the deterioration of a range of cognitive tasks when a supplementary task occupies the processing capacity of the system even though such tasks do not have an obvious STM component. WM is a limited capacity memory system that also influences learning, comprehension, and reasoning (Baddeley, 1986). The Atkinson-Shiffrin model however, only makes predictions regarding cognitive activities that are short-term in nature. The capacity of the STS is restricted to tasks affecting STM activities. It would be speculative therefore, to predict how the Atkinson-Shiffrin model would explain why other non-STM cognitive tasks are affected by a STM activity.

Both similarities and differences exist between Baddeley's working memory and Atkinson-Shiffrin's memory model. The differences, however, represent a shift in emphasis from structure to function. STM refers to a whole class of memory tasks in which the amount of material to be remembered is relatively small and the delay between presentation and test is in the order of seconds rather than minutes. Baddeley (1986) states it is implausible however, to assume that tasks fulfilling this requirement all depend exclusively on the operation of a single processor or system (i.e. STS). The WM model represents a STM modification that is characterized by a move from a strategy of exploring the capacities and implications of a single hypothetical structure (STS) toward a more complex multi-component concept (WM) (Baddeley, 1990) and a more functional analysis of memory (Baddeley, 1986).

Many memory models are conceptualized using data collected and obtained through verbal memory studies. The to-be-remembered items include letters, words, phrases, stories, and pictures. The Atkinson-Shiffrin model and WM model, in particular the articulatory loop, are no exceptions. Researchers conduct memory experiments using modalities other than the verbal modality however, (e.g. movements) and apply the existing memory models to the data. Indicative of this approach is the field of motor memory.

MOTOR MEMORY

Motor memory became a topic of study after the inception of the Brown-Peterson paradigm in the late 1950's (Brown, 1958; Peterson and Peterson, 1959). The majority of motor memory research (eg. Adams and Dijkstra, 1966; Diewert, 1975; Ho and Shea, 1978; Laabs, 1973; Marteniuk, 1973; Pepper and Herman, 1970; Posner and Keele, 1970; Posner and Konick, 1966; Stelmach, 1969) utilizes the experimental paradigm of verbal memory studies with the major exception being the inclusion of a movement as the to-be-remembered item. Subjects are presented a standard or reference movement and asked, after some period of delay, to later reproduce the movement. No feedback is given to the subject and the error associated with the reproduced movement is measured. The term motor memory became associated with those experimental paradigms that investigate the encoding and retention factors affecting memory of movements, with the underlying assumption that the movement per se is being recalled as a single unitary whole (Adams and Dijkstra, 1966; Posner and Konick, 1966; Stelmach, 1969).

The one-item experimental paradigm resulted in the interpretation of the data being based on concepts derived from the verbal memory literature. Memory models, such as the Atkinson-Shiffrin model and Baddeley's WM model, can be applied to the data of movement memory experiments resulting in different conclusions. When attempting to apply both models to memory for movements, the difference in coding type becomes relevant. Research has shown that movements appear to be encoded and remembered based on certain characteristics such as speed, acceleration, duration, and extent (Smyth and Pendleton, 1990; Wickelgren, 1977). The notion that movements are coded based upon their spatial properties allows the application of Baddeley's WM. The visuo-spatial sketch pad can be accessed directly through visual perception or indirectly through the generation of a visual image (Baddeley, 1990). The sketch pad handles information that is either visually or spatially presented and spatially encodes that information. The Atkinson-Shiffrin model, however, states that all information is phonologically coded. Hence, movement characteristics (eg. speed, acceleration, extent) would be transferred to a verbal code in the STS. Although transforming movement information to a phonological code is questionable in relation to a spatial code, the Atkinson and Shiffrin explanation can not be totally disregarded.

Unfortunately, the research on movement memory did not produce results that could contribute to a theory of motor memory (Wilberg, 1990). Often, more than one verbal memory model could appropriately explain the memory for movement literature. This is evident with the two memory models in relation to a coding explanation. One model may be more favourable but both are equally viable. The one-item long experimental paradigm, therefore, was utilized for numerous studies in the 1960's and 1970's but motor memory research seems to have decreased in popularity in the 1980's and 1990's.

One possible reason for the decline in research in the movement memory field, may be the inconsistent use of relevant terms. Wilberg (1983, 1990) addresses this concern, and as a result differentiates between the terms motor memory and memory for movement; motor memory refers to the process of how whereas memory for movement refers to the activity of what. If, for example, a person is asked to move their arm in a sequence of three moves in a specified order and direction, the activity of reproducing the moves in the desired sequence is the memory for movement task. On the other hand, the actual underlying process controlling how to move the arm is the motor memory task. Subjects do not consciously call upon their motor memory to retrieve the movement process(es) necessary to successfully complete this task but they do consciously decide what actions to perform. Process refers to the implementation of the specific choices and not to the volition associated with the desired moves (Wilberg, 1983).

Given the 'motor memory-memory for movement' distinction, it may be fair to say that most memory experiments requiring the reproduction of a movement appear to be investigating memory for movements rather than motor memory. Investigators employ the one-item long memory task and ask subjects to reproduce the movement. Subjects need only to recall what movement needs to be performed in order to be successful in this task. Successful performance, however, does not require the recollection of the process associated with the volition. "Process plays the role of an interpretive structure, expressing the to-be-remembered movement in terms of time and motion" (Wilberg, 1983; p. 44).

Another possible reason for the disappearance of memory for movement research may be the inconsistent conclusions that have resulted from the limited Brown-Peterson type of paradigm (Wilberg and Adam, 1985). The approach of encode, store, retain, and retrieve an item is limited to the investigation of one item at a time. As mentioned earlier, this paradigm has frustrated researchers because of the failure to contribute to an adequate theory of motor memory. A new approach to examining memory for movements can be found by adapting the running memory paradigm, first used by Kirchner (1958), and applying it to memory for multiple actions.

EXPERIMENT 1

This new experimental manipulation investigates the short-term retention of movement information by requiring continual monitoring of an ever-changing stimulus display, thereby constantly updating the information that resides in memory. In this task, a subject is asked to recall old items from memory while simultaneously encoding and storing a new item in memory. The subject is presented movement items one at a time until a predetermined load has been achieved. Once the maximum load size has been achieved, a new item is presented and the subject is asked to recall the first movement item and consequently remove the first item from memory, store the new item, and maintain the fidelity of the remaining items. The same pattern of replacing old items with new items continues until the end of each trial. The number of items residing in memory will be held constant since the new items will replace the outgoing old items.

The modified-Kirchner paradigm will be called the back memory paradigm since subjects are required to recall an item a certain number of positions back in memory. The back memory approach allows for investigation into an active memory whereby more than one movement item must be manipulated concurrently. Previously, memory for movement experiments did not require subjects to encode and store a new item while recalling an old item. A more passive memory is involved when the task demands are to encode a new item first, then store the new item, and finally recall it. The memory system is not active but static in this one-item situation since very few processing demands are required. In a back memory task, the subject must actively manipulate the items in memory to retrieve the correct response and encode and store the new response. Perhaps the modified running memory paradigm more closely resembles the every day operation of memory than the old one-item long paradigm, and may help clarify some issues that have been held in obscurity for some time.

Several investigators have employed the running memory paradigm and have generally found that some memory capacity exists, evidenced by complications when completing the task. The percentage of correct responses decreases as the memory load (or the number of items back) increases (Hockey, 1973; Kirchner, 1958; Nixon, 1948; Pollack, Johnson, and Knaff, 1959; Wilberg, 1987). Wilberg (1987) used movements as the to-be-remembered items, and found that as the back memory load increased, subjects became less precise (i.e. more variable in spatial error). Further, this finding was accompanied by an increasing size in error with progressively larger loads.

The purpose of this study is to utilize the back memory paradigm to investigate the effect of increasing load upon memory for multiple movements. The back memory task requires the subject to manipulate and store more than one item concurrently, and therefore, utilizes an active memory system that is not limited to only one movement item. In a previous back memory study (Wilberg, 1987), subjects were eliminated from the experiment at the time of committing an error, resulting in a limited number of subjects (n=4) that attempted the higher loads. In order to obtain an accurate assessment of the effect of load upon memory for movements, all subjects, in this experiment, will perform all back memory conditions allowing for comparison between the varying loads.

Method

Subjects. Thirty-two individuals from the general university population volunteered as subjects in the experiment. The subjects ranged in age from 19 to 38 years.

Apparatus. The equipment used was a digitizing tablet (Supergrid) equipped with a hand held stylus and interfaced with a PDP 11/10 computer. The tablet recorded samples to the nearest 1000th of an inch. Beneath the Supergrid was a stimulus board consisting of 8 lights (not visible to the subject). Six of the lights were arranged in a circular manner with the other two inside the circle (see Figure 3). Subjects were naive as to the number and location of the lights. The lights were programmed to appear one at a time in random order.

Procedure. Subjects were given verbal instructions explaining the task, and a demonstration on how to use the apparatus. Subjects were required to move the hand held stylus to a stimulus location on the digitizing tablet. The subjects were unaware as to the exact number of stimulus lights beneath the board and to their location. Given that the apparatus was novel to all

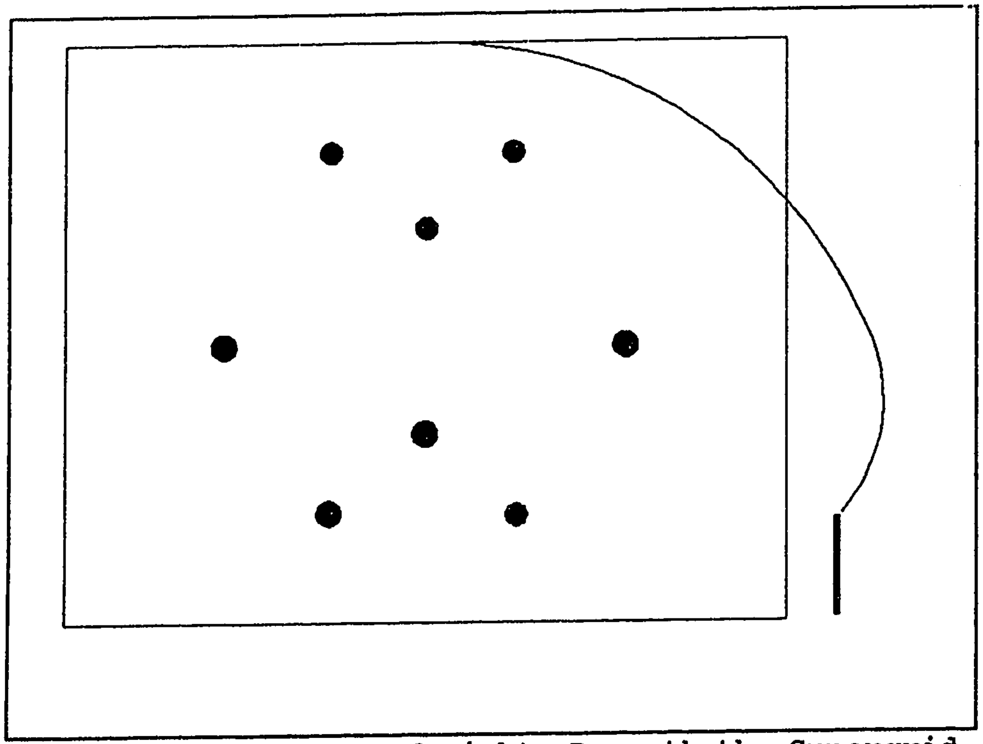

Figure 3 The Pattern of Lights Beneath the Supergrid.

subjects, a brief period of time was allowed for familiarization with the equipment and the task demands.

Subjects performed a total of 10 blocks with each block consisting of the four separate conditions. In each block, the subject progressed from the least demanding memory load (the control condition) to the largest memory load (3-back condition). Each condition was performed until a maximum of 10 movements had occurred or until an error was made. Movements were considered errors if they failed to meet two criteria: 1) the area around the target and 2) the movement distance.

Required movement distances could have been one of six possibilities (8.25 cm, 12.70 cm, 14.00 cm, 18.40 cm, 24.80 cm, and 25.40 cm). Wilberg (1990) discussed using only those movements that met the exact specifications as the target movement as the only true reproduction of the original movement. This notion was considered unrealistic and reproductions were allowed to deviate from the required movement by certain percentages and still be considered valid. It was concluded that an acceptable bandwidth for a memory for movement type experiment is ± 20%.

In this experiment, the first criterion for a correct movement was area around the target light. If the target movement length was 10 cm, subjects were allowed to be within a radius of 2 cm of the target (given the bandwidth). However, subjects also had to move the required distance within a certain range. This calculation took into consideration the beginning spatial location and the end spatial location. For example, light A and light B were 10 cm apart. On the movement to light A, the subject undershot the target by 2 cm. On the following movement to light B, the subject overshot the target by 2 cm. The subject has now moved a total distance of 14 cm. However, the required movement was only 10 cm, and with the correction factor of ± 20%, an acceptable movement length would be between 8 and 12 cm. According to the first criterion, the movements to both target lights could be deemed correct. However, this movement exceeded the distance criteria of 8 to 12 cm and would therefore be considered an error in this experiment. Without the second criterion for determination of error, this movement could erroneously have been deemed correct since it met the requirements for area around the targets. Once a movement was considered to be an error, the condition was terminated and the next condition was initiated.

Subjects were required to withhold a motor response until either 0,1,2, or 3 discrete items had been accumulated and then commence serial recall. The number of movements to be held in memory defined the different conditions. In the 0-back condition (control), subjects were instructed to move the stylus to the location of the illuminated light and remain at that position until the next stimulus light appeared, at which time the task was to move the stylus to the new location. In all instances, the stimulus light remained on for a total of

2 seconds. In the _1-back_ condition, the first stimulus light was accompanied by a tone. Subjects were instructed to remain on the home position until the second stimulus light was turned on, and then proceed to the location of the first light (i.e. the light that had just been turned off). When the third light was illuminated, subjects were required to move the stylus to the position that was occupied by the second light. In the 1-back condition, subjects were always moving one light behind the illuminated light. Similarly, in the _2-back_ condition, subjects were always two lights behind, moving to the location of the light that had been extinguished two lights previously. This resulted in the first movement occurring when the third light was turned on (the first two lights were accompanied by a tone). The last condition required subjects to move to the spatial location of the light that was illuminated 3 stimuli previously, hence it was called the _3-back_ condition. Once again, subjects remained stationary while the first 3 lights and corresponding tones occurred, and proceeded to move to the first light when the fourth light appeared. In all conditions (except the control condition), subjects were required to encode and

store new items while at the same time recalling old items from memory.

Statistical Analyses. The initial analyses consisted of a set of 2-way ANOVA's (4 back levels X 10 blocks) for all correct responses and a set of 2-way ANOVA's (3 levels X 10 blocks) for all incorrect responses with treatment (back memory load) and block (1 to 10) being the independent variables for both sets of analyses. The incorrect responses included only the back conditions of 1 to 3 because errors were not committed in the 0-back condition for any of the subjects. The dependent variables involved the use of absolute error (AE), calculated by subtracting the location of the light from the location of the response and taking the absolute value. For both correct and incorrect responses, AE was calculated for the x-coordinate, the y-coordinate, and a combination of the x and y values called radial error (RE). Radial error was calculated by subtracting the location value of the response from the location value of the light for both the x- and y-coordinates. The radial error is the hypotenuse of the triangle formed by the x- and y-values and calculated by:

$$RE=\sqrt{(X^2 + Y^2)}$$

The total number of movements to error per condition was also analyzed as a dependent variable. The post hoc comparisons of means were performed on significant main effects and interactions using the Tukeyb method at the $p < 0.05$ level.

Results

The analysis of variance revealed a significant main effect of memory load for radial error on incorrect responses, $F(2,43)=15.10$, $MSe=26.457 \times 10^5$, $p < 0.0001$. (see Figure 4) The 3-back memory load condition was significantly different ($p < 0.05$) than the 1-back and 2-back conditions, which did not differ from each other. The mean radial error was 2.33 cm, 3.23 cm, and 4.88 cm, for the 1-back, 2-back, and 3-back conditions, respectively. The ANOVA also showed a significant memory load main effect for radial error on correct responses, $F(3,93)=35.26$, $MSe=76825.59$, $p < 0.0001$. (see Figure 5) For those movements that were considered correct in the 0- and 1-back conditions, the mean radial errors, respectively, were 1.54 cm and 1.57 cm, and these differed significantly ($p < 0.05$) from the 2- and 3-back conditions, 1.90 cm and 2.00 cm, respectively. No other main effects or interactions for radial error were significant ($p > 0.05$).

One other main effect that revealed significant results of memory load was the number of movements to error per condition, $F(3,93)=818.86$, $MSe=5.23$, $p < 0.0001$. Further analysis revealed that there was a

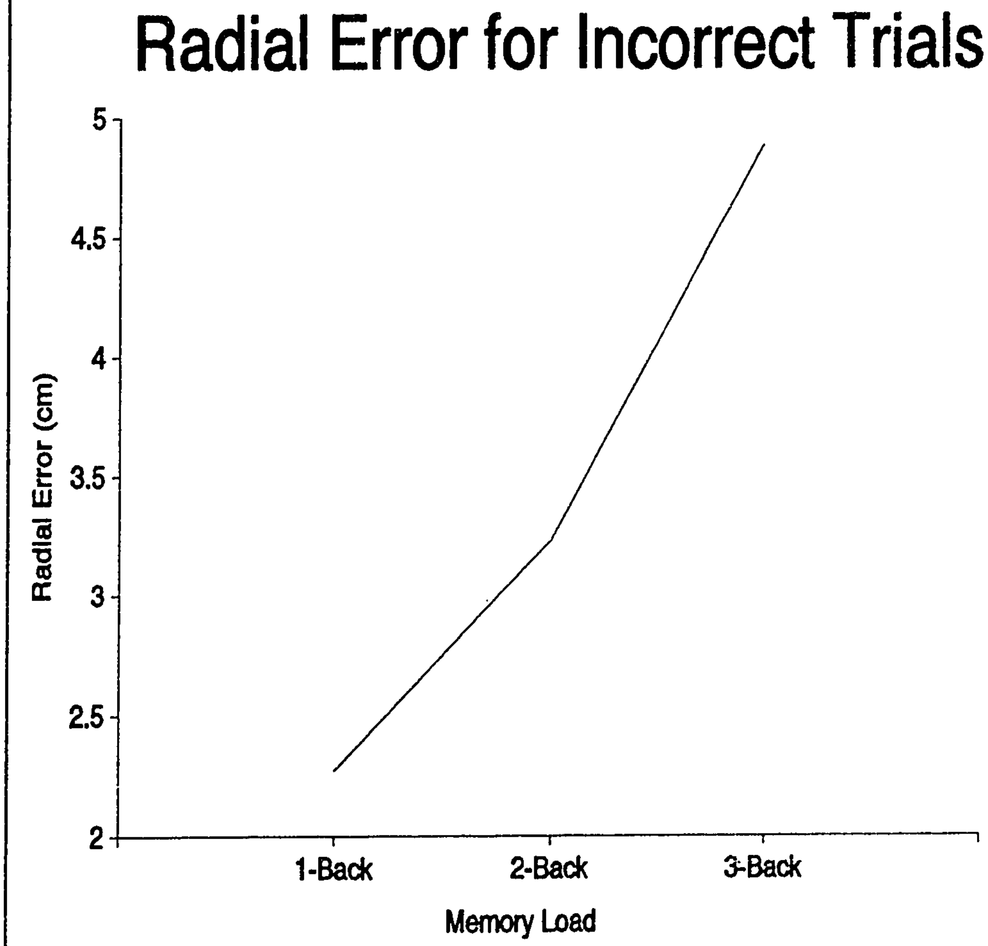

Figure 4. Experiment 1 - Radial Error for Incorrect Trials

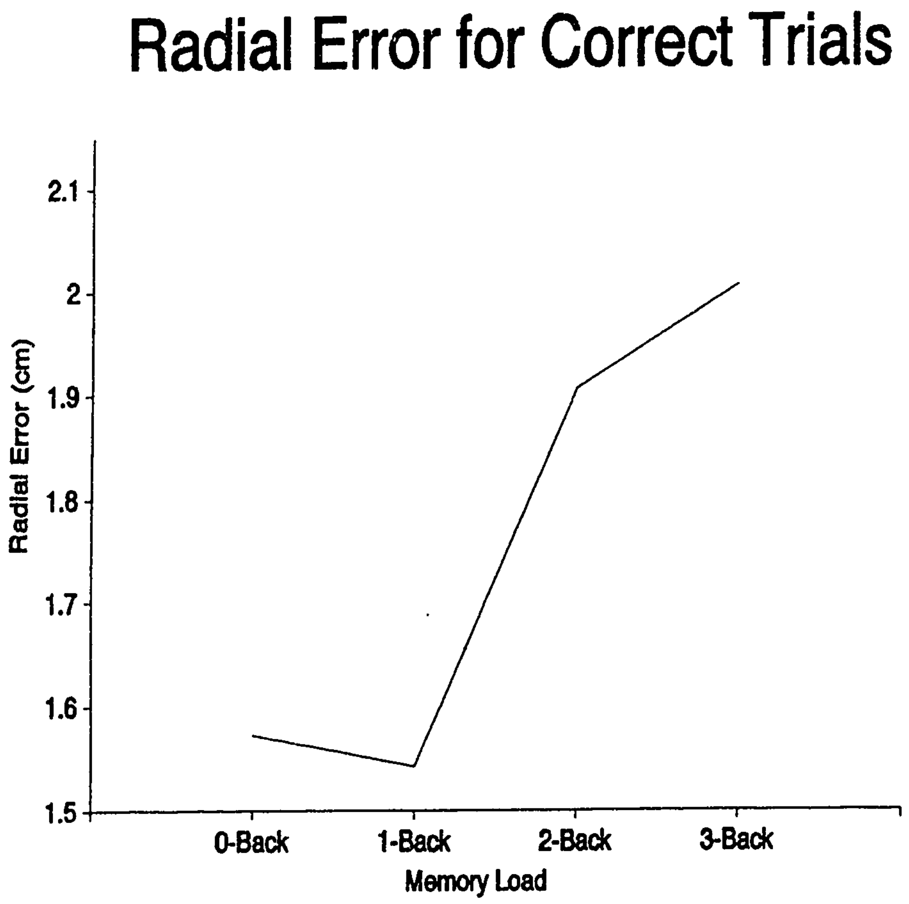

Figure 5. Experiment 1 - Radial Error for Correct Trials

significant difference between all four memory load conditions (see Figure 6). The mean number of responses per memory load for the 0-, 1-, 2-, and 3-back conditions were 10.00, 9.52, 3.70, and 3.19, respectively.

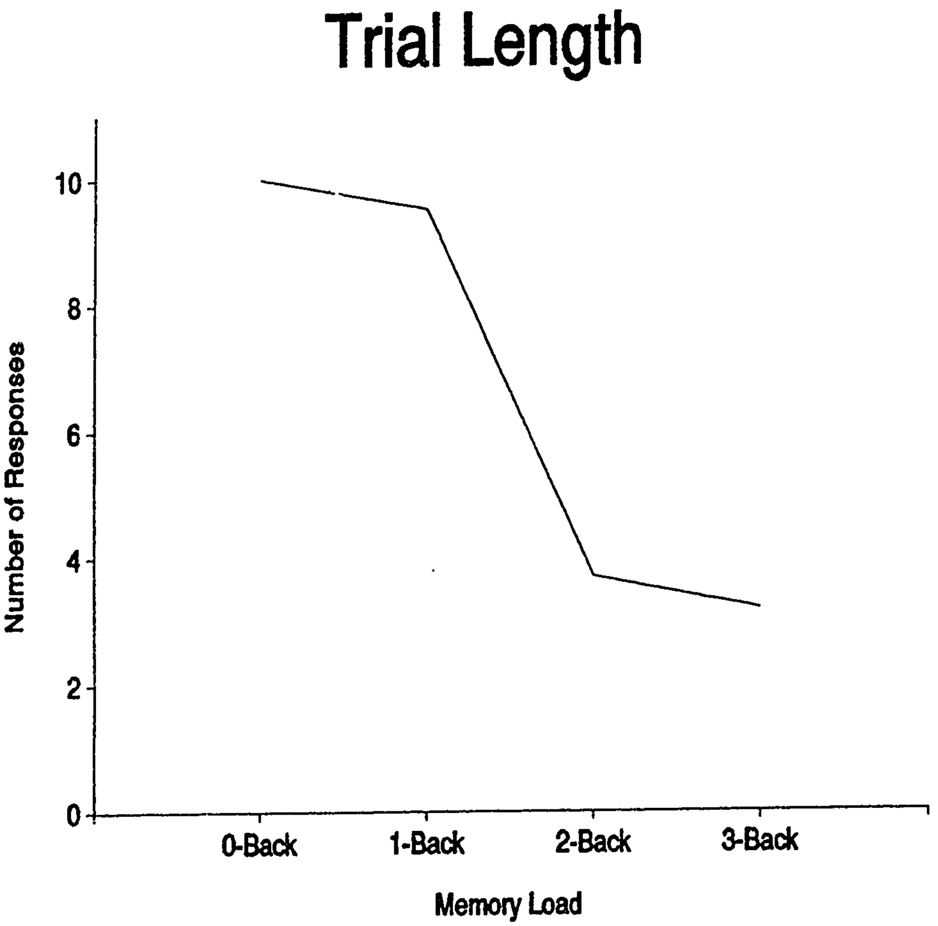

Figure 6. Experiment 1 - Number of Responses Per Trial

Discussion

In this experiment, it appears that forgetting occurs when the loss of spatial precision becomes too large. At this point, the subjects lose the item producing successively larger spatial location errors. Further, the maximum size of this error appears to be a monotonic function of the load. A similar increase in error with an increase in load was reported in a previous study as well (Wilberg, 1987).

The analysis for radial error reveals that with increasing memory load there is a resulting decrease in accuracy, for both correct and incorrect responses. When subjects were performing the task correctly, according to the pre-established criteria, the size of the movement deviation (radial error) from the target light became larger as the load upon memory increased. The same pattern of larger error production with greater demand is also found in the responses that fell outside of the criteria for a correct movement. Regardless of the movement's correctness, radial errors increase with increasing load.

The present experiment shows that as memory load increases, the subject's ability to correctly respond while successively capturing new items significantly decreases. The limited capacity of the memory system appears to be having an effect on the individual's ability to respond correctly. The subject has difficulty coping with the increased demands placed upon the memory system when asked to perform under varying load conditions. Although, the power and storage of memory seem endless, the occasional constraints placed on memory are often severe enough to impede human performance (Wickens, 1984).

Traditionally, capacity has been investigated using a memory span task. Miller (1956) provides evidence to indicate a capacity to process information in the range of seven plus or minus two items. Chase and Ericsson (1982) report a memory span of three to four items. MacGregor (1987) states that the limits of memory could be four or six depending upon the model and level of organization used in the experimental manipulation. Wilberg and Girard (1977) and Girard and Wilberg (1977, 1980) indicate span to be 3 movement items. Researchers cannot agree on the length of span since ambiguous results are found depending upon the type of item used in the memory task. In all instances, span is only a function of the capacity of the system. Klapp (1982) states that span memory does not make use of all of the capacity of working memory hence, span is only reflective of the capacity and not equivalent to it. (For a further discussion on the nature of limited capacity see Appendix A.)

It has been assumed in the past (eg. Atkinson and Shiffrin, 1968) that while operating within the capacity of the memory system, no performance decrements should occur. However, once outside the limits, errors in recall increase dramatically. The back memory paradigm theoretically allows subjects to operate within their capacity (maximum number of items held at any one time being only 3), yet performance decrements are still being observed. The question now becomes, how do the two memory models discussed earlier interpret the results of the back memory study?

The Atkinson-Shiffrin model contains a rehearsal buffer of a maximum size of 5 to 8 items. As the buffer reaches maximum capacity, any new items entering the STS will enter the buffer and the old items will drop out of memory. The scenario describing the operation of the rehearsal buffer appears to mimic the activity required when one performs the back memory task. One obvious problem is that the buffer does not appear to reach the maximum size of 5 to 8 items in this task. Atkinson and Shiffrin, however, do not provide a definition for "item". Perhaps, a single movement is comprised of a number of items, thereby resulting in one movement being equal to more than one item.

Also, in the back memory task more than just storage of items is required. The Atkinson-Shiffrin model accommodates this notion. If the STS is required for other processing then the size of the buffer is reduced in order to free up resources for the new processing requirements. This would explain why the buffer appears to be operating below the maximum size capacity in this active memory paradigm.

The back memory paradigm seems suited for investigating the memory model of Baddeley (1986). WM is an active memory system responsible for both manipulating and storing of items. The slave systems are not limited by the number of items in memory but by the durability of the information they contain. Baddeley believes that forgetting occurs when the system is overloaded in processing demands. The back memory paradigm could be viewed as putting many processing demands upon the working memory system. The subject must encode, store, retrieve, and retain items concurrently. As the demands increase (i.e. as the load increases), the WM is overloaded causing the system to forget.

From the previous discussion, it is clear that both memory models could adequately explain the data. Therefore, in order to assess the differences between the Atkinson-Shiffrin memory model and the Working Memory model, another test needs to be employed. A common method used to depict differences between various attentional models could be employed here; namely, the use of dual tasks. Peters (1991) states paradigms incorporating a competition for 'resources' (of whatever kind) best express the underlying mechanisms of the systems involved. The implication being that the secondary task requires some of the limited attentional capacity, thereby causing performance decrements on one or both of the tasks involved. If subjects were asked to do a secondary task while performing the back memory task, a discrepancy between the predictions of both models would exist.

The Atkinson-Shiffrin model would predict if the primary task occupied the full capacity of the system, a secondary task would not be possible unless the primary task (the back memory task) suffered significantly. Clearly, the back memory task operates at full capacity as the load increases and performance errors become greater. The resources of the STS would have to be shared resulting in either an inability to achieve the secondary task requirements or a large decrease in performance level of the primary task. In order for both tasks to be performed concurrently, response deficits would have to occur in one or both tasks.

Baddeley would predict that a secondary task would only conflict if it competed for the use of the same slave system as the back memory task. The primary task may be affected but only marginally if different processes are being utilized. Smyth and Pendleton (1990) argue that the visuo-spatial sketch pad is involved when recalling movements. If this is true, a secondary task requiring spatial coding should significantly impair the back memory task whereas a non-spatial task should have little effect. The Atkinson-Shiffrin model would predict that both secondary tasks should have a significant effect since the capacity is limited by size and not processes. If the primary task occupies the full capacity of the system, then <u>no</u> secondary task could accompany the task unless the primary task performance suffered significantly.

EXPERIMENT 2

The following experiment is designed to investigate the effect, if any, of a secondary task on the primary back memory task. If movements are operating within the sketch pad then it would be reasonable to assume that a non-spatial task would not have any effect on the back memory task. Further, non-spatial tasks, verbally based or not, should not have an effect on the primary task. The important point made by Baddeley is that the tasks will interfere if the control processes interfere and, if the tasks require the same type of coding. The secondary tasks, will therefore, be one of three types: a verbal task but not spatially dependent (articulatory suppression), a verbal task but spatially dependent (counting backward by threes), and a motor task but not spatially dependent (rapid tapping task).

Baddeley (1986) reports the use of articulatory suppression in the investigation of the WM model. The continuous recycling of a single word (eg. "the" or "la") places demands upon the articulatory loop but not the central executive (Vallar and Baddeley, 1982). If the back memory task is affected by the repeating of a single word, then arguably the articulatory loop must be involved in this back memory task. If, on the other hand, no decrements are observed in the back memory task, the involvement of the articulatory loop in movements can be questioned.

Wickelgren (1977) reports that in a dual task situation the counting backward task interferes greater with a spatial task than with a purely verbal task. He argues, therefore, that counting backward by threes "appears to involve some type of spatial as well as verbal representation" (p. 294). Further, the counting backward task appears to be related to the spatial position more than to spatial movement. Hence, if the backward counting task interferes with the back memory task, the importance of spatial coding in the sketch pad may be implicated.

The task of rapidly tapping may be considered a control for the other two tasks. The tapping task is not believed to be very dependent on spatial organization. The subject is asked to tap in one spot, as rapidly as possible for a period of time. Tapping in one spot could be considered the movement equivalent of articulatory suppression. The subject will be required to continuously recycle the same movement (a finger tap) in the same location. Central executive involvement should be minimized in this task as it is in the articulatory suppression task. Since the spatial location demands are minimized in tapping, if the tapping task results in severe back memory decrements, the spatial coding explanation of memory for movements may be suspect and may have to be reexamined.

Finally, the Atkinson-Shiffrin model would predict that if one task is operating at maximal capacity then another task would not be possible unless both tasks showed poor performance. This experiment may help to further discriminate between the Atkinson-Shiffrin model and Baddeley's working memory model.

Method

Subjects. Fourteen individuals from the general population at the University of Alberta volunteered as subjects in this experiment. The subjects ranged in age from 23 to 35 years and all were self proclaimed right handed.

Apparatus. The equipment used is the same as in Experiment 1. The Supergrid digitizing board is interfaced with a PDP 11/10 computer. There are 8 lights beneath the board in the same pattern as in the first experiment.

Procedure. Subjects received verbal instructions explaining the task demands, and a demonstration on how to use the equipment. Given that the apparatus was novel to all participants, subjects were given a practice block of trials in order to familiarize themselves with the task of moving a hand-held stylus to a stimulus location on the digitizing tablet. In addition to the movement task, subjects also were required to perform three other tasks: an articulatory suppression task, a counting backward task, and a tapping task. The procedures for these tasks were also explained and demonstrated to the subjects.

The experiment involved the subjects participating on two separate days. The first day consisted of the performance of all four tasks singly and independent of one another. The second day of testing involved the performance of the movement task (the primary task) in combination with the other three tasks. A within-subjects design was used as all subjects receive all conditions.

Single Task Conditions. The primary task in this experiment is the back memory task. The procedure was identical to that in Experiment 1 with the exception that 5 blocks of the four back conditions (0-back to 3-back) were given to the subjects. All subjects receive all of the back conditions as in the first experiment and the same criteria are used to determine if the movements to the stimuli are correct. The secondary tasks are the articulatory suppression task, the counting backward task, and the rapid tapping task.

The articulatory suppression task involved the subject repeating the word 'la' during the entire experimental condition. In the single task situation, subjects were asked to repeat the word 'la' for a total of 20 seconds on 5 separate occasions. Responses were counted and a measure of the number of responses per second was calculated.

In the counting condition, subjects were verbally given a 3-digit number and asked to count backward by threes from that number for 20 seconds. Subjects were prompted with a beep to respond every 2 seconds. This procedure was repeated 10 times. Subjects were instructed to count backward from their last response regardless if they committed an error or not. If, for example, the subject's responses were 328, 325, then 323. The correct response, given the instructions, should be 320. If this was the response of the subject then only one error would be counted in this trial (given all the remaining responses were correct). The dependent measure for the counting backward condition was the number of counting errors that were made by the subject for every 10 numbers.

The rapid tapping task required the subjects to continuously tap their left index finger for a period of 20 seconds. Tapping commenced and at the sounding of a beep. This procedure was completed five times. Instructions stipulated that subjects tap at a rate that would be continuous and constant. All five trials were averaged per subject to give a measure of tapping rate per second.

The order of the tasks was counterbalanced across all subjects.

Dual Task Conditions. On day two, subjects were asked to combine the primary task with the secondary tasks. During the dual task condition of the back memory task coupled with articulatory suppression, subjects were required to begin the repetition of the 'la' as soon as they heard the warning tone. They were to continue to repeat the word during the back memory task until the end of each trial was reached. Subjects performed five blocks of the back memory-articulatory suppression task with each block consisting of the four back memory conditions. The dependent measures were the same as those for the single task conditions.

The counting backward-back memory dual task condition involved the subject receiving a 3-digit number at the warning sound and giving the next response at the illumination of each stimulus light. Thus for the 1- to 3-back conditions subjects still responded with the next 3-digit number in the sequence even when the first light(s) did not require a physical response to the stimulus. Stimulus lights occurred every 2 seconds therefore number responses were given at the same pace as in the single task condition. Five blocks of all 4 back memory conditions were performed and the two tasks were measured in the same fashion as in the single task situation.

In the final dual task condition, subjects were asked to begin tapping at the sound of the warning tone and continue to do so until the end of each back memory trial. Subjects were reminded of the rate at which they performed in the single task situation and asked to try to maintain that rate. As in the other dual task conditions, subjects performed 5 blocks of all back memory conditions. Similar measurements were taken on both the back memory and tapping tasks as in the single task condition.

The order of dual task condition was counterbalanced across all subjects.

Statistical Analyses. The initial analyses consisted of a set of 3-way ANOVA's (5 blocks X 4 back levels X 4 sessions) for all correct responses and a set of 3-way ANOVA's (5 blocks X 3 back levels X 4 sessions) for all incorrect responses. The independent variables for all sets of analyses were block (1 to 5), back memory condition (0-back to 3-back), and session (one single task and 3 dual task). The incorrect responses were analyzed separately because no errors were made on the 0-back condition and thus this variable had to be eliminated from the analysis. Secondary tasks were analyzed using 2-way ANOVA's with session (single versus dual) and back load condition (4 levels) being the independent variables.

The dependent variables were radial error, response time, and total number of responses per trial for the back memory task. For the secondary tasks, counting rate, tapping rate, and speaking rate were calculated as the dependent measures.

Radial error was measured for the correct and incorrect responses. Response times were measured from the onset of a stimulus light to the completion of the next response, whether correct or incorrect. The number of responses per trial was either 10 responses if the subject did not commit an error or measured by the number of responses made per back memory condition before the trial was terminated by an error.

Counting rate was measured by the number of errors made during the 10 responses in the single task condition and extrapolated to responses in the dual task condition if the subject responded less than 10 times. Tapping rate was calculated by counting the number of responses and dividing by the time to result in the number of responses per second for the single and dual situations. Similarly, speaking rate was calculated for the number of responses per second for both dual and single task conditions.

Another set of 3 way ANOVA's (3 sessions X 4 back loads X 5 blocks) was performed on difference scores for all correct responses. Difference scores were calculated by subtracting the single task value of radial error, response time, and trial length from the comparable dual task scores. A similar 2-way ANOVA (3 sessions X 3 back loads) analysis was performed on the dependent variables for incorrect trials. This analysis was collapsed over blocks since there were no earlier significant effects found for the dependent variable. Also, as before, the 0-back load condition was eliminated from this analysis as no errors were made during this treatment.

All post hoc comparisons of means were performed on significant main effects and interactions using the

Tukeyb method at the $p < 0.05$ level.

Results

Correct Trials

The analysis of variance revealed a significant two-way interaction (session X memory load) for response times on correct trials, F(9,114)=3.64, MSe=32145.73, $p < 0.001$. (see Figure 7). Post hoc analysis indicated that the slowest response times overall were at the 0-back memory load. As the number of items in memory increased response times decreased in the same manner for all of the tasks except for the counting backward task. The response time for the counting condition decreased significantly from 0-back to 1-back and did not significantly change thereafter as in the other sessions. However, the decline in response rates was not as great as in the other sessions and the response times for the 3-back condition did not differ from the 0-back condition for the counting session only. In the other sessions, there was a significant decline in response times from 0-back to 1-back and significant differences exist between the other memory loads and the 0-back condition.

Also for correct trials, there was a significant memory load main effect for radial error, F(3,39)=121.77, MSe=92995.56, $p < 0.0001$. Post hoc tests indicated that

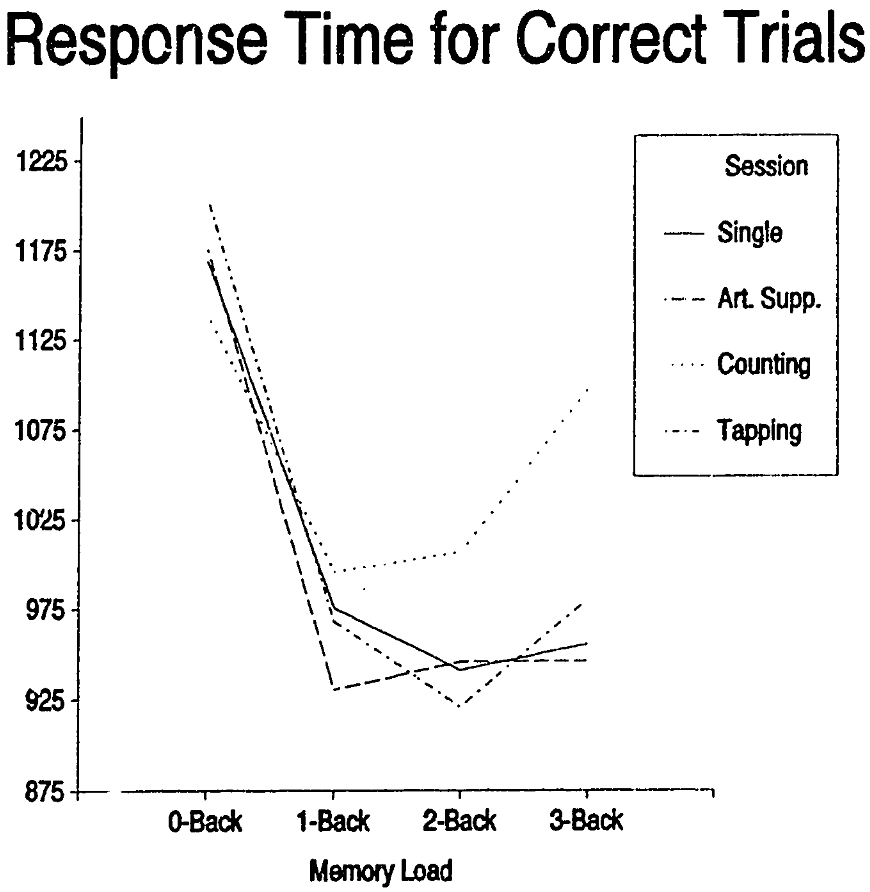

Figure 7. Experiment 2 - Response Times for Correct Trials.

all four treatments differed significantly ($p < 0.05$) from each other. (see Figure 8)

A significant 2-way interaction was found for the number of responses per trial, F(9,114)=2.32, MSe=3.55, $p < 0.02$. (see Figure 9) Post hoc analysis revealed that subjects [illegible] had fewer responses with increasing memory load. [illegible]ver, when subjects had to count backward by th[illegible]s, while performing the primary task, fewer responses occurred than at any of the other sessions for all of the memory loads except the 0-back condition. The counting condition caused the greatest decrement in the number of responses per trial per memory load.

Incorrect Trials

Analysis of variance on the incorrect trials revealed two significant main effects for radial error: a treatment effect (memory load), F(2,23)=5.71, MSe=55.675 X 10^5, $p < 0.01$, (see Figure 10), and a significant session main effect, F(3,42)=8.14, MSe=15.287 X 10^5, $p < 0.001$ (see Figure 11). Tukeyb tests indicate that radial error for the 2-back condition ($\overline{X}$=3.05 cm) was significantly less ($p < 0.05$) than the radial error for the 3-back condition ($\overline{X}$=4.48 cm). Further, the

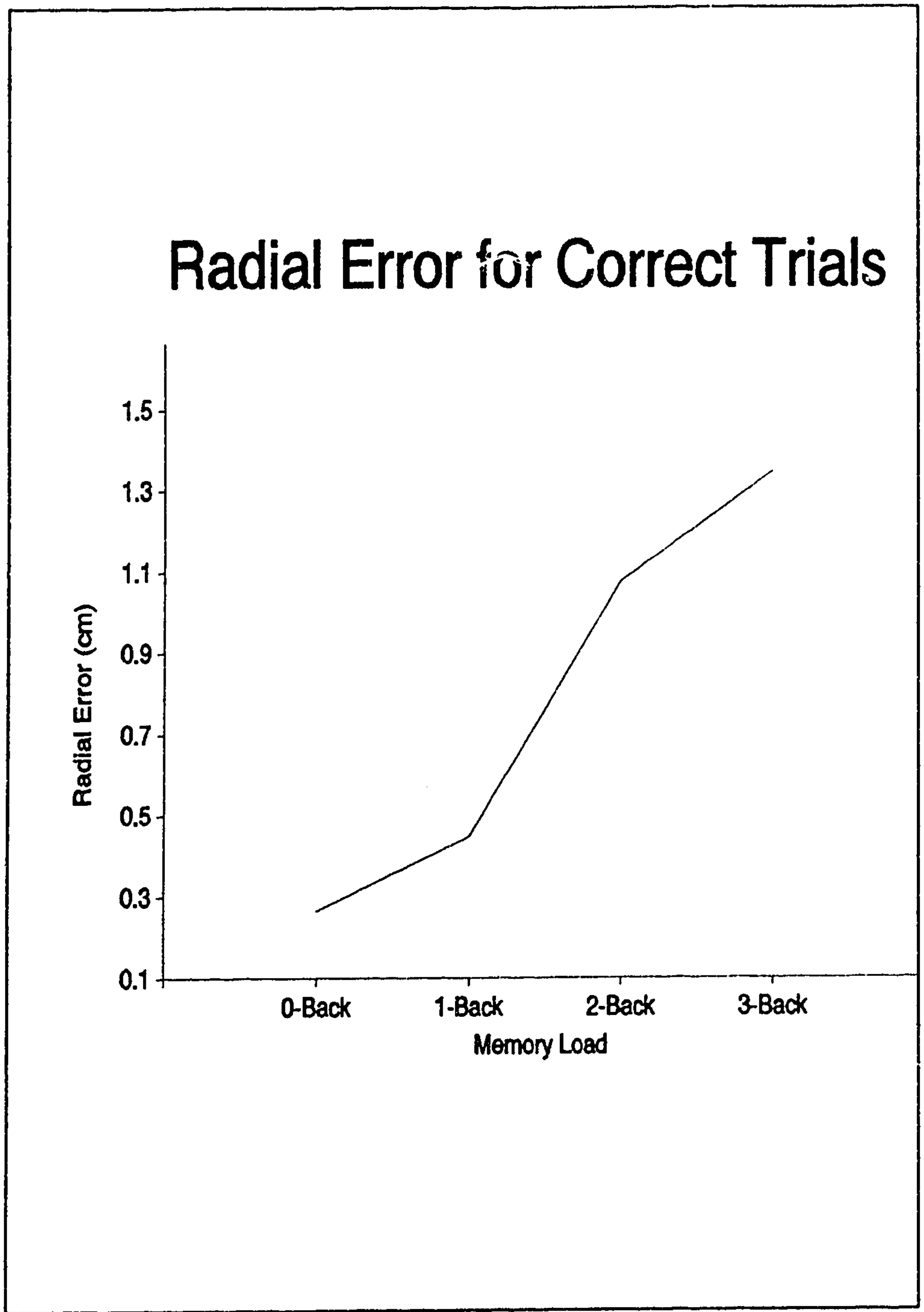

Figure 8. Experiment 2 - Radial Error for Correct Trials.

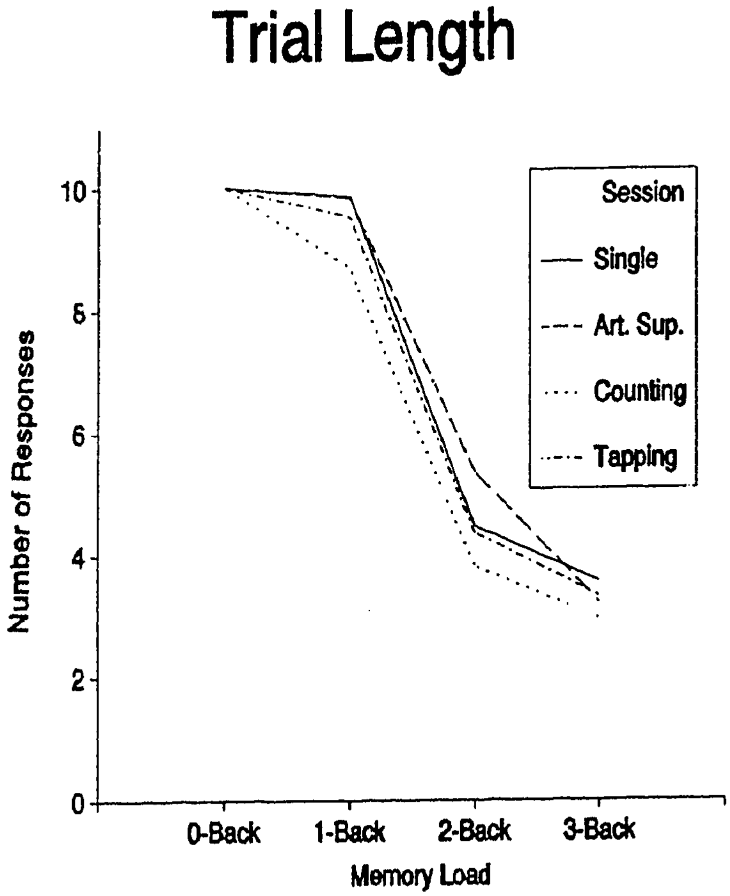

Figure 9. Experiment 2 - Number of Responses Per Trial.

radial error in the dual condition of counting coupled with the "back memory" primary task was significantly greater ($p < 0.05$) than the other 3 sessions which in themselves did not differ.

ANOVA's on the response times of incorrect trials revealed 3 significant main effects and no significant interactions. A main effect for session was found, $F(3,42)=6.04$, $MSe=190913.01$, $p < 0.001$ (see Figure 12). The mean response time for the counting dual task condition ($\bar{X}=1123$ msec) was significantly ($p < 0.05$) slower than the other 3 conditions. The single task session ($\bar{X}=955$ msec), the tapping dual task session ($\bar{X}=975$ msec), and the suppression dual task session ($\bar{X}=923$ msec) did not differ between themselves.

The second main effect for response times was for treatment condition (memory load), $F(2,23)=4.53$, $MSe=50920.48$, $p < 0.02$ (see Figure 13). The mean response times for incorrect trials were 1136 msec, 1007 msec, and 971 msec, for the 1-back, 2-back, and 3-back treatments, respectively. Post hoc tests revealed the 1-back condition was significantly ($p < 0.05$) slower than the 3-back condition.

Finally, there was a main effect for block,

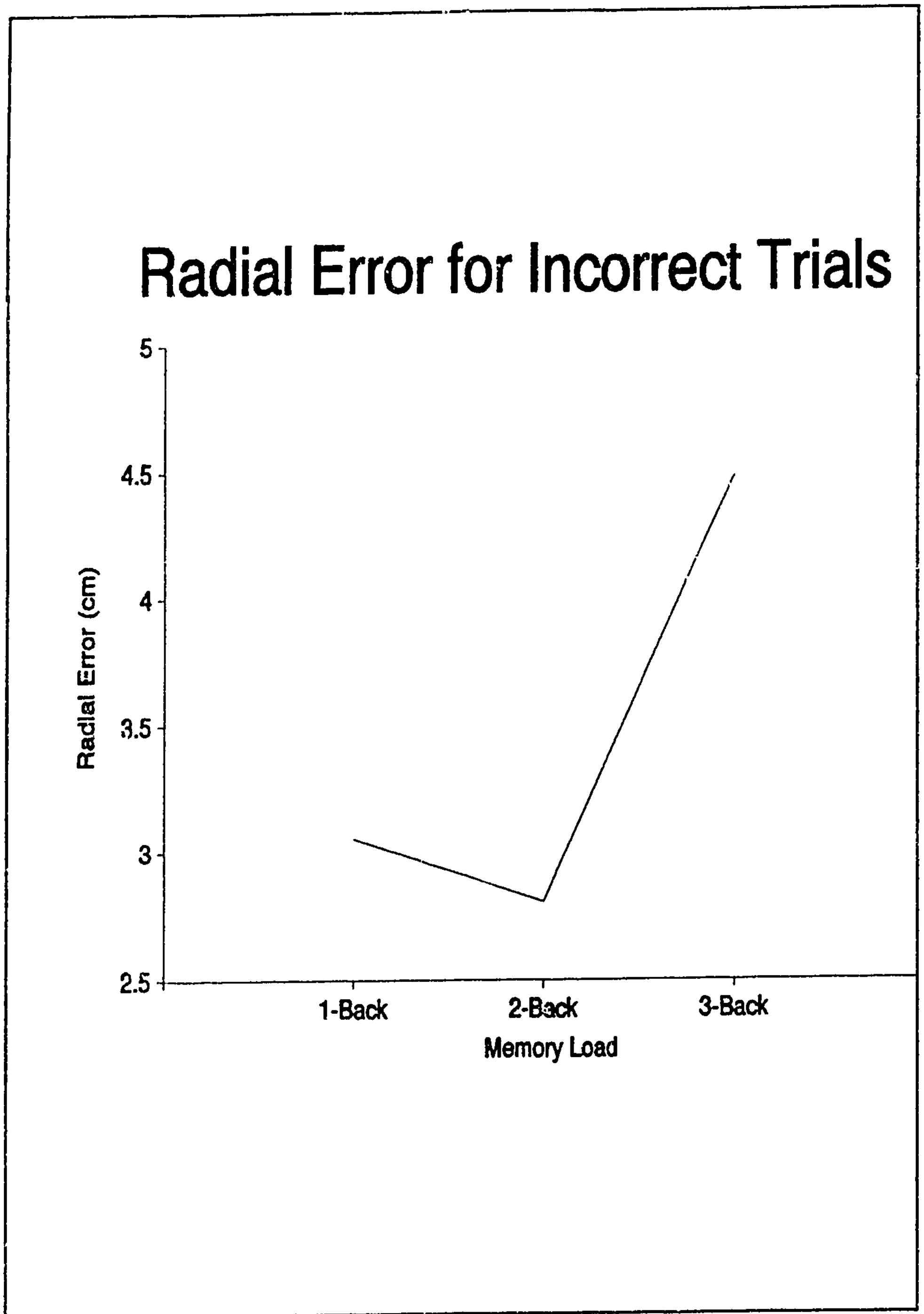

Figure 10. Experiment 2 - Radial Error for Incorrect Trials - Load Main Effect.

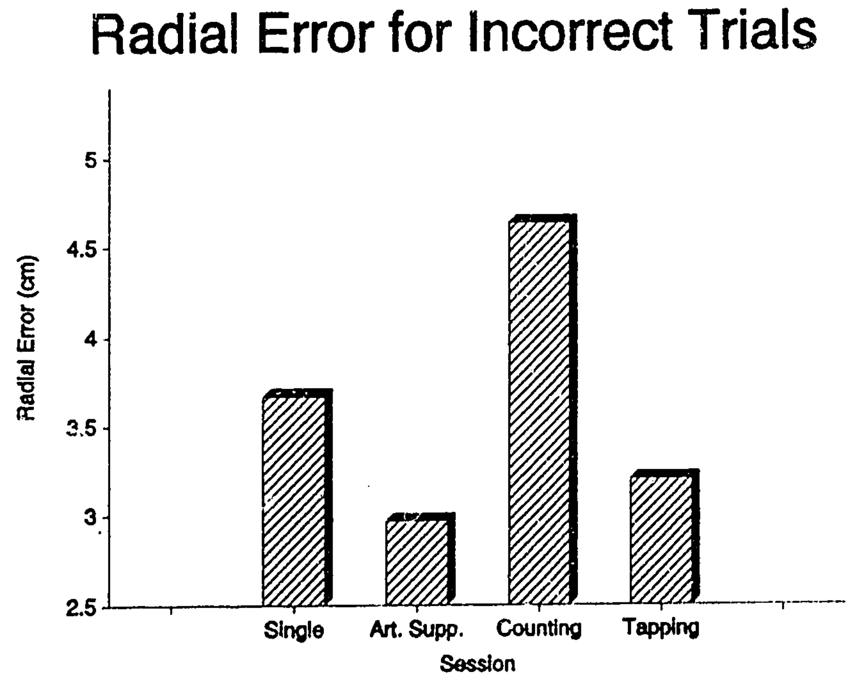

Figure 11. Experiment 2 - Radial Error for Incorrect Trials - Session Main Effect.

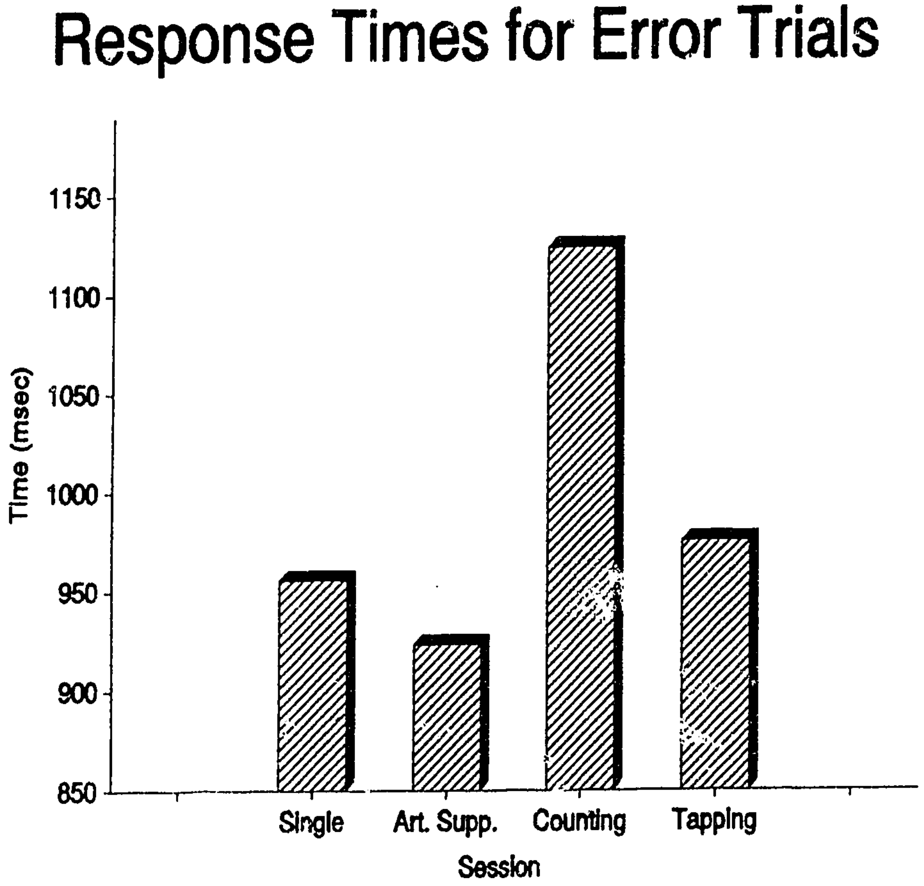

Figure 12. Experiment 2 - Response Times for Incorrect Trials - Session Main Effect.

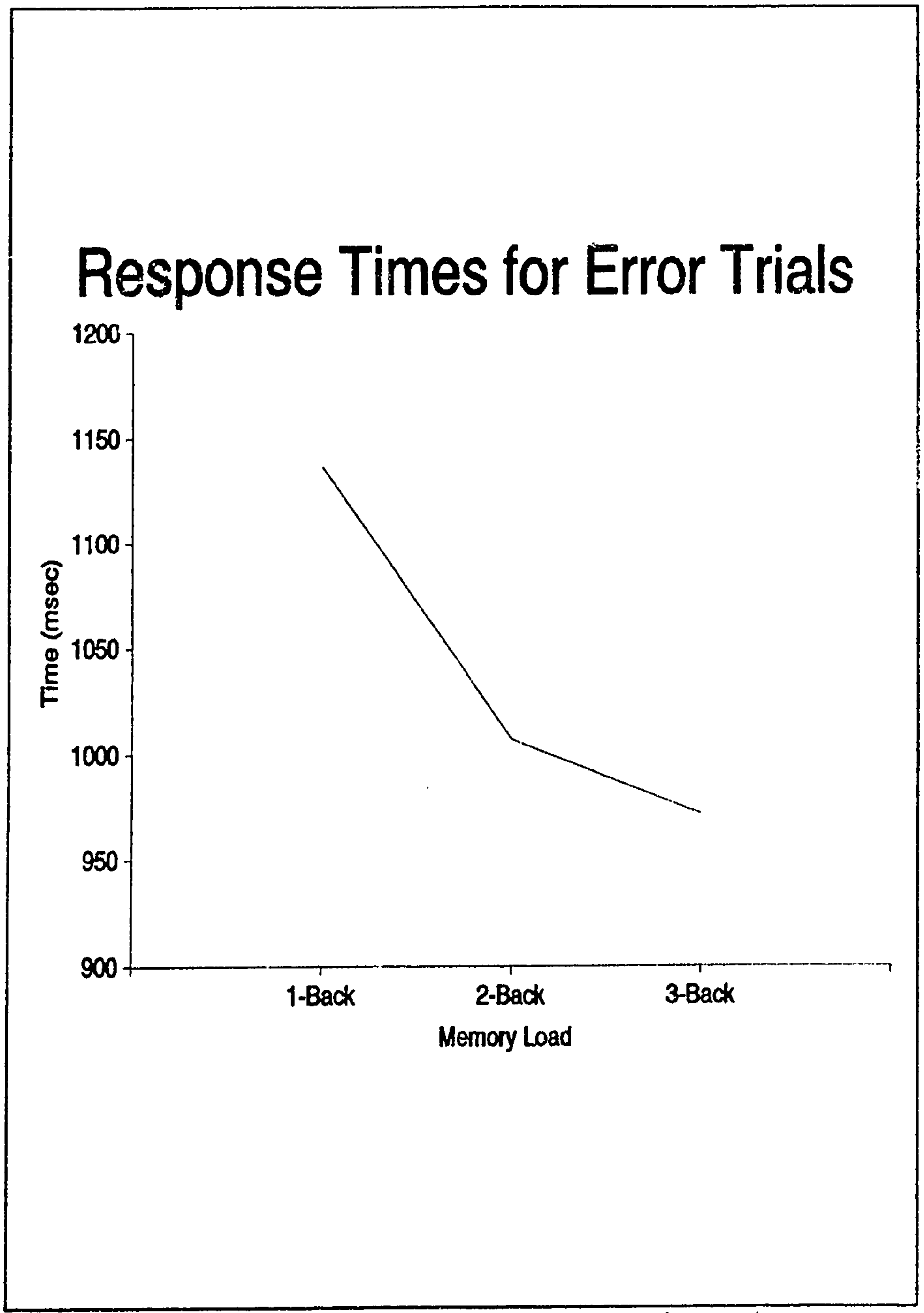

Figure 13. Experiment 2 - Response Times for Incorrect Trials - Load Main Effect.

$F(4,52)=3.66$, $MSe=49551.38$, $p < 0.01$, however, post hoc analysis failed to show any significant differences ($p > 0.05$) between the 5 blocks of trials.

Difference Score Analysis

Analysis of the difference scores for correct trials revealed a significant 2-way interaction for response time, $F(6,76)=5.35$, $MSe=29159.53$, $p < 0.001$ (see Figure 14). Tukeyb analysis indicated that the difference scores utilizing the counting response times were significantly different between the memory loads of 0-back and 3-back. No other post hocs were significant.

The difference score analysis also indicated a 2-way interaction for trial length, $F(6,76)=2.70$, $MSe=3.80$, $p < 0.05$ (see Figure 15). The three memory load conditions (1-, 2-, and 3-back) of the counting session were significantly different than the 2-back load in the articulatory suppression session. Further post hoc analysis also revealed that the 1-back memory loads differed between the articulatory suppression and the counting sessions.

The ANOVA for difference scores on incorrect trials revealed a significant session main effect for response time, $F(2,26)=6.92$, $MSe=44707.01$, $p < 0.01$ (see Table 1).

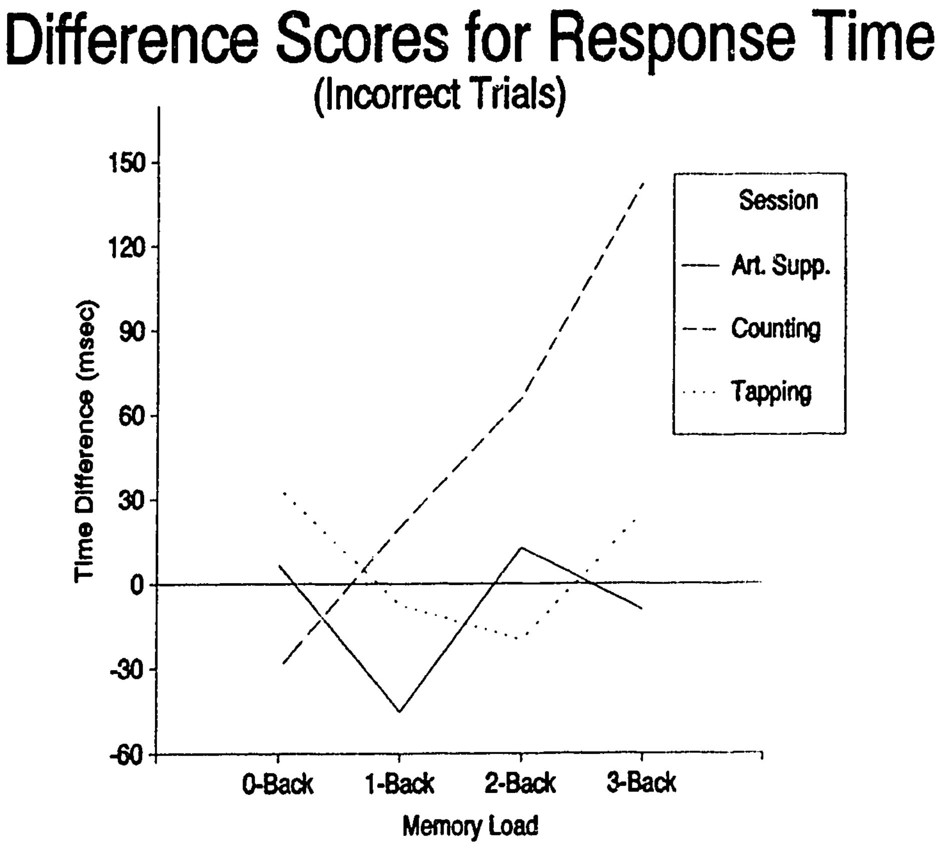

Figure 14. Experiment 2 - Difference Scores for Response Times of Correct Trials.

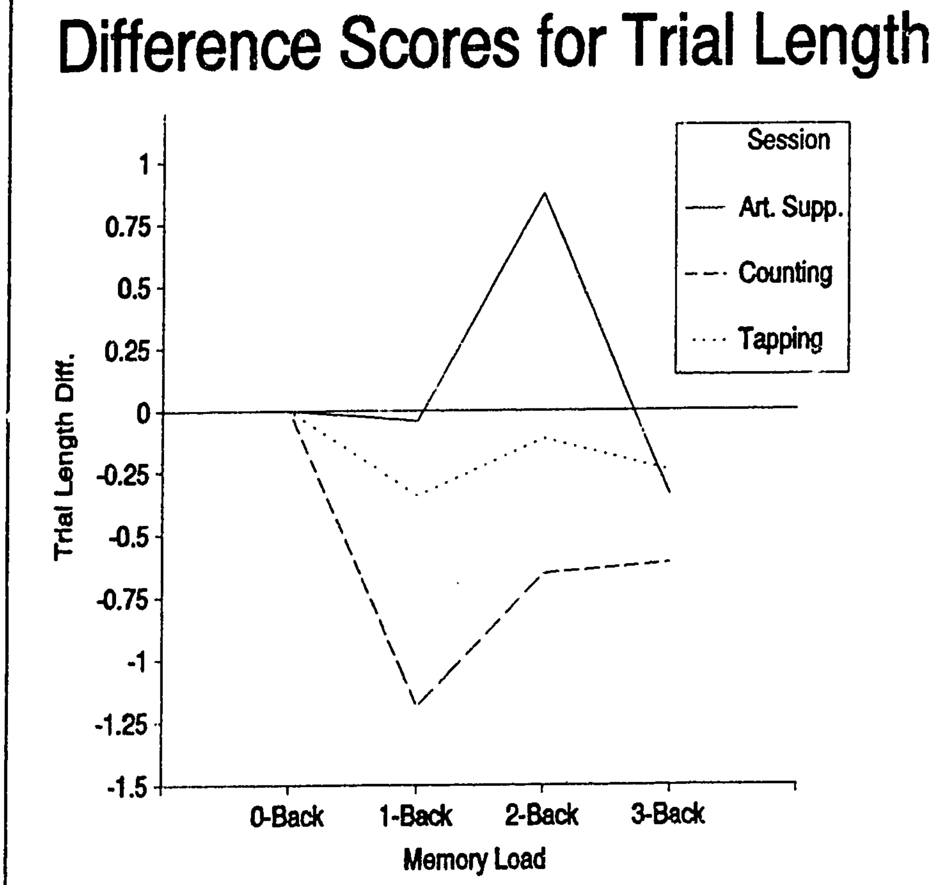

Figure 15. Experiment 2 - Difference Scores for Number of Responses per Trial.

Post hoc tests indicate both the articulatory suppression and the tapping session have significantly smaller time differences than the counting session.

The difference scores for radial error on incorrect trials also showed a significant main effect for session, F(2,26)=15.52, MSe=317173.99, $p < 0.001$ (see Table 1). Tukeyb tests reveal the counting session has significantly larger radial error differences than the other two sessions.

Table I
Difference Scores for Incorrect Trials.

	Articulatory Suppression	Counting Backward	Repetitive Tapping
Response Time (msec)	-45.057	155.256	6.761
Radial Error (cm)	-0.71	1.19	-0.46

Secondary Task Analysis

The ANOVA revealed a memory load main effect for tapping rate, F(4,52)=3.10, MSe=.05, $p < 0.05$ (see Table 2). Tapping rate was slower ($p < 0.05$) for the 1-back condition than for either the 2-back condition or the 3-back condition. No other differences between any of the sessions were found for tapping rate.

The analysis of variance showed a significant main effect of memory load for counting errors per ten numbers, $F(4,52)=5.63$, $MSe=.17$, $p < 0.001$ (see Table 2). The number of counting errors at the 2-back memory load and the 3-back load was significantly higher ($p < 0.05$) than at the 0-back memory load. No other significant differences ($p > 0.05$) for number of counting errors were made between any of the other sessions.

Analysis of the secondary tasks revealed no significant differences for articulatory suppression rate ($p > 0.05$) (see Table 2).

Table II
Secondary Task Analysis

	Single Task	0-Back Load	1-Back Load	2-Back Load	3-Back Load
Art. Supp. Rate (/s)	1.72	1.59	1.47	1.55	1.65
Counting Errors	0.40	0.08	0.32	0.66	0.73
Tapping Rate (/s)	2.16	2.15	2.03	2.25	2.32

Discussion

All the secondary tasks utilized in this dual task experiment caused performance decrements in the back memory task, however, the greatest overall interference in this experiment appears to be associated with the secondary task of counting backward. The articulatory suppression task and the tapping task did have interference effects on the back memory task but they are only minor. In fact, in most instances, subjects performed remarkably similar during the single task session and during the secondary task situations with the exception of the counting backward situation. All dependent measures used reveal that counting backward had deleterious effects on memory for movements.

Examination of the total number of responses per trial shows the counting condition to have the least number of responses at any of the back memory loads except the 0-back load where none of the conditions differed (see Figure 9). Subjects could not successfully perform the task for as many responses in the verbal-spatial dual task condition than in the other conditions. The counting task disrupted performance to the greatest extent.

Another way of examining the trial length results is to note the results of the difference score analysis (see Figure 15). The bottom line on the graph depicts the counting session minus the single task session. Clearly, this line shows that the counting session always had less trials than the single session and less trials than any of the other two secondary task sessions. The articulatory suppression and the tapping sessions had similar trial lengths to the single task session with the major exception being the 2-back memory load for the articulatory suppression treatment.

One final way to depict the number of responses made would be to sum the total number of errors for all subjects (see Figure 16). This graph highlights the counting backward condition to have its greatest influence on the 1-back memory load. The secondary tasks, with regard to total number of errors in the experiment, have a similar interference effect on the back memory task at the 2- and 3-back memory loads. A large difference, however, between the secondary tasks is exhibited at the memory load of one item behind.

The interference caused by counting backward also manifest itself in the dependent variables associated

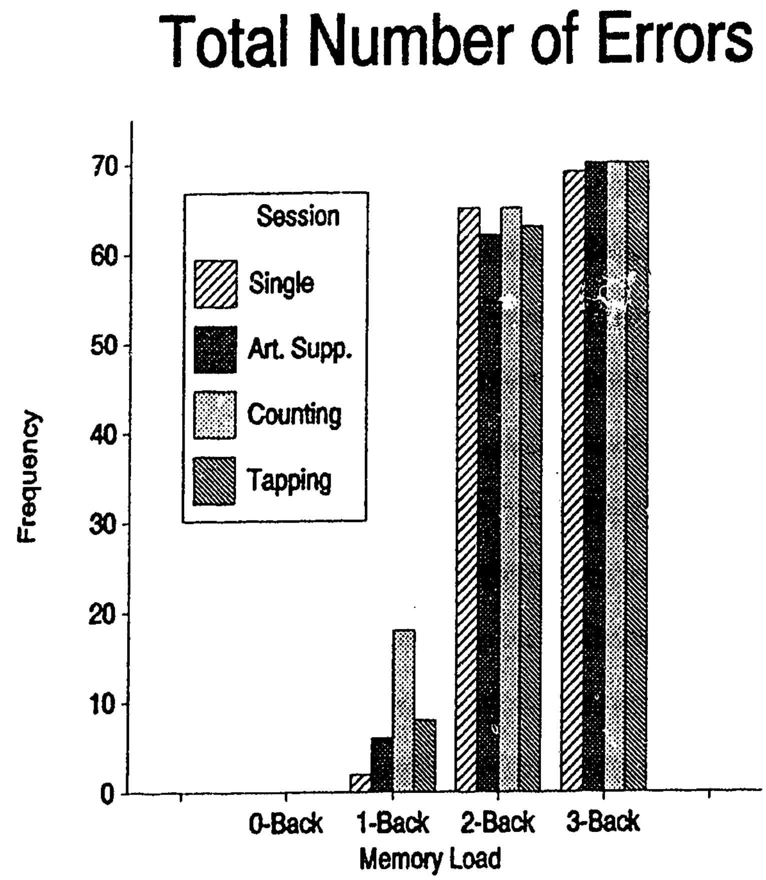

Figure 16. Experiment 2 - Total Number of Errors Made by All Subjects.

with incorrect trials. The slowest response times accompanied the counting session while the other three sessions were relatively the same (see Figure 12). The difference scores (see Table 1) emphasize the degree to which the counting session was slower than the single task situation. As well, they highlight the similarity existing between the other two dual task sessions and the single task situation. The only significant response time differences exist when subjects had to count backward by threes while performing the back memory task. Once again, counting backward resulted in a large interference effect on the back memory task.

Incorrect trials also differed for response time depending upon the memory load. As subjects progressed from the load of one movement to three movements, response times decreased. This suggests that subjects offload a movement quicker if the memory load is large. By responding quicker, subjects are allowing themselves more time to control the remaining cognitive processes required for the other movement items in memory. Similar results are reported by Wilberg (1966), who found that as memory load increased subjects decreased their reaction time. Kantowitz (1974) reports a number of studies that show the secondary task decreased the time to perform the primary task and called this effect facilitation. Facilitation suggests the primary task is simplified or assisted in the presence of the secondary task. This type of explanation is doubtful in the present experiment except for the notion that the faster times facilitate by allowing more processing time to be directed to completion of the back memory task.

The radial error scores for incorrect trials showed that with increasing memory load subjects increased the size of error. A significant increase in loss of accuracy occurs between the memory loads of 2- and 3-back (see Figure 10). The 1-back condition has an error similar to the 2-back condition. This was not found in the previous experiment, where very few errors were even made at 1-back. There were more errors committed in the second experiment (n=34) but not nearly as many as in the 2-back (n=255) or 3-back (n=279) conditions. Also, the errors committed were very large due to an absolute loss of the item in memory for this memory load. The size of the error coupled with the fewer occurrences of errors resulted in what appears to be a large accuracy loss. What once was a relatively simple condition becomes highly complicated in the presence of a secondary task, hence errors are very large.

Radial error not only increases with increasing memory demands, it also differs depending upon which secondary task accompanies the primary task (see Figure 11). The largest radial error scores for incorrect trials are found for the counting session. The other two dual task situations, the articulatory suppression and the tapping sessions, have similar radial error scores to the single task situation.

The difference scores assist in interpreting the radial error results (see Table 1). The counting minus single task score (in absolute values) is the largest of any of the three groups. The negative values for the other two sessions indicate the single task session actually had larger errors than the two other dual task situations. These differences, however, are not significant.

Analysis of the correct trials display a similar pattern of results. The two-way interaction for response time (see Figure 7) reveals that while performing the counting task (with the back memory task), subjects never achieve the response rate of the other sessions. The difference graph (see Figure 14) depicts these same results and highlights the effect of increasing memory load. Subjects in the counting session became successively slower while during the other two sessions they remain relatively the same as during the single task session.

The radial error scores for correct trials showed that subjects became more errorful with increasing demands on their memory system (see Figure 8). This result is similar to the effects found in the first experiment (see Figure 5). The loss of spatial accuracy becomes greater with increasing memory loads. No effect of secondary task, however, proved significant for radial error for correct responses. This could possibly be due to t small criterion range allowed for correct trials. There is very little room for deviation from the target for the response to still be considered correct. Although radial error differences do exist, large variances would eliminate any significant differences.

How do the predictions of the two memory models hold up to the results of this dual task experiment? The Atkinson-Shiffrin model predicts no secondary task would be possible if the primary task occupies the full capacity of the system. In order for the two tasks to occur concurrently, one or both tasks would suffer performance decrements. This would be true regardless of the nature of the secondary task because the Atkinson-Shiffrin model is limited by size and not processes. The Working Memory model (Baddeley, 1986) predicts the performance of a secondary task is possible if the secondary task and primary task utilize different slave systems. In this situation, the primary task will only be marginally affected by the presence of another task.

The dominant theme in the results of the second experiment is the overwhelming interference that occurs during the dual task session utilizing the secondary task of counting backward by threes. The tasks of tapping and articulatory suppression could be considered less difficult than the counting task and therefore, no interference effects are found with the primary task. These secondary tasks, although seeming to be less demanding, have been shown in the past to have detrimental effects on primary tasks. Kinsbourne and Hiscock (1983) provide an extensive review of the dual-task literature in which tapping is reported to interfere in numerous studies. Similarly, Baddeley (1986, 1990) provides several examples of primary task interference caused by articulatory suppression. In the second experiment, therefore, it is reasonable to assume all three secondary tasks have the potential to equally interfere with the back memory task.

The pattern of results seem to favour the predictions of the Baddeley WM model rather than the Atkinson-Shiffrin model. Subjects were able to perform two tasks simultaneously on two occasions and had difficulty accomplishing the task on only one occasion. Atkinson-Shiffrin would have predicted similar results for all 3 secondary tasks. There should not be differential results depending on the type of secondary task according to the Atkinson-Shiffrin memory model. Baddeley, however, does allow for the performance of two tasks concurrently, as long as the tasks require operation of different slave systems. Given the results, Baddeley's model would argue that the counting task and the memory for movement task must share similar underlying mechanisms. The tapping task and the articulatory suppression task, however, would not be competing with the back memory task for use of the same slave system.

The task of counting backward by threes has a high spatial and verbal representation (Wickelgren, 1977). According to Baddeley (1986, 1990), if two items interfere with each other, they must be competing for control of the same processes and, further, they must have similar codes. Given the degree and extent of interference encountered in the primary back memory task, the type of processes underlying memory for movements must have some involvement of either spatial coding, verbal coding, or both.

The articulatory suppression task has been shown to place demands upon the articulatory loop (Vallar and Baddeley, 1982) which encodes information of a phonological nature. Baddeley (1986) reports a number of studies in which articulatory suppression has a large interference effect upon a verbal task. Repeated recycling of the word 'la', however, had no effect on the back memory task performance in the second experiment. Thus, the involvement of verbal (phonological) coding in memory for movements must be questioned. Since counting backward has the potential to involve both spatial and verbal coding, and since the articulatory suppression results predict no verbal involvement, one must conclude that the movements in these experiments have a spatial representation.

GENERAL DISCUSSION

In the dual task experiment, as in the first experiment, it appears that forgetting occurs when the loss of the spatial accuracy becomes too large. When this occurs, subjects lose the item and produce increasingly larger errors. The analyses for both correct and incorrect responses for both experiments reveal that accuracy is lost with increasing demands placed upon the memory system (see Figures 4, 5, 8, and 10).

The purpose of the second experiment was to investigate the effect of a secondary task on the primary task. The first experiment alone could not lend insight into the nature of representation of the movements used in these memory experiments. By noting the patterns of interference associated with the various secondary tasks, inferences are made regarding the primary task. In the present experiment, three different tasks were used to interfere with memory for movements. The greatest interference effect as evidenced in all dependent measures accompanies the counting backward condition. The patterns of interference in the second experiment support the notion that memory for these movements has a high reliance upon spatial representation.

The spatial coding explanation could be extended to the involvement of the visuo-spatial sketch pad (VSSP) in Baddeley's model of working memory. The VSSP, while being the least explored slave system, is believed to be important when planning spatial tasks (Baddeley, 1990). The majority of tasks used to investigate the VSSP have involved the use of imagery. The task employed in this experiment, memory for movements, suggests perhaps movements are represented and manipulated in the VSSP as well. This conclusion, although requiring further investigation, has been previously suggested (Smyth, Pearson, and Pendleton, 1988; Smyth and Pendleton, 1990).

The two experiments reported here also contribute to the central executive (CE) component of Baddeley's WM model. Baddeley (1986) states the central executive is the least understood element of the model partly because of its high integration with the slave systems. It is very difficult to isolate the central executive and its operations without involving one or both of the slave systems. Since the major role of the central executive is to coordinate cognitive processes, Morris and Jones (1990) state the only viable test of the central executive would be a "dynamic memory task" that requires dynamic processing while utilizing the storage and operation of the slave system. The running memory task satisfies these requirements because subjects must maintain the fidelity of the old items, encode new items, and recall old items concurrently (Morris and Jones, 1990).

The back memory paradigm, an adaptation of the running memory paradigm, also requires the same processes and hence could be considered an adequate test of the central executive. Dobbs and Rule (1989) state the back memory paradigm studies the flexibility of the central executive while attenuating storage and processing demands. Li (1991) reports increases in lag (memory load) result in increases in the storage requirements while the necessary processing routines remain unchanged. Increasing storage demands affect the slave systems while the control of processing demands affect the central executive.

Morris and Jones (1990) state the dynamic memory task is properly investigating the central executive provided no interaction exists between the secondary task and number of updates (i.e. increasing load). An interaction suggests a greater load is placed upon the memory, and this does not meet the requirements for an adequate test of the central executive. The processing demands must be dynamic and constant while storage demands must increase in order to investigate the central executive. An interaction would suggest the processing demands have increased such that there is no longer an independence between the slave system and the central executive.

In the second experiment, the results reveal main effects for secondary task and memory load, with the exception of an interaction for trial length (Figure 9) and an interaction for response time for correct trials (Figure 7). The incorrect trials depict main effects on both dimensions for both response time and radial error. When subjects commit an error, accuracy lessens with increasing load, while being affected differentially by the secondary task. Therefore, according to Morris and Jones (1990), the back memory task would appear to be an adequate test of the central executive.

Dobbs and Rule (1989) believe the 1-back condition to be a good indicator of central executive functioning since storage demands are minimized yet repetitive shifts in processing are still demanded. In the 2- and 3-back conditions storage demands increase and may cause interference with the processing requirements. In the first experiment the difference between the 1-back and 2-back memory loads is enormous. It is difficult to assess central executive performance from the first experiment alone. However, when a secondary task is added, the greatest influence is reported at the 1-back condition.

Although the 2-back and 3-back conditions are affected by the secondary task, it is the 1-back condition that is significantly affected by the presence of secondary tasks (compared to the single task situation). Figure 16 shows the large number of errors committed at the one back condition for the different secondary tasks. The counting condition, which caused interference similarly across memory loads, has a huge influence particularly at the 1-back load. Morris and Jones (1990) propose that mental arithmetic involves an executive mechanism due to a reliance on coordination of routines. The control processes utilized during counting backward require operations similar to that of the central executive. A significant detriment, therefore, occurs at the 1-back condition when counting backward because the arithmetic interferes with central executive functioning.

The presence of a secondary task disrupts the operation of the central executive. The present experiments report that similar tasks can disturb central executive functioning as evidenced by the high interference effect at the 1-back memory load for the counting backward dual task condition. The back memory paradigm appears to provide a task that permits investigation into central executive functioning.

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APPENDIX A

The Nature of Limited Capacity

The exact nature of the capacity of short term memory has eluded understanding for many years (Schweickert and Boruff, 1986). Part of the problem lies in the fact that capacity is always investigated using a memory span manipulation. The length of memory span is highly related to the type of item used in the span task. Perhaps the tasks are changing depending on the material, resulting in inconclusive data. Shimp (1976) states that a given behaviour may be a functional unit in one context and not in another context. This is illustrated in an experiment by Murdock (1961) in which subjects are asked to recall one of three types of stimuli after a given delay. The stimuli were: single three-consonant trigrams (3 letters), single monosyllabic words (3 letters), or three monosyllabic words (9 letters).

The results indicate that percent correct was higher for the single words than for the trigrams. This is not an unexpected finding. However, for the last stimulus type, the three words, the results are identical to the trigrams. The functional unit has changed. If each letter is presumed to represent a unit, the results would expectedly differ. The first two stimuli would produce similar findings with both being superior to the third stimulus type.

When nine letters, grouped into three words, are presented, however, subjects use the pattern of letters and not the individual letters themselves to solve the problem, producing results similar to and not inferior to the first stimulus type. The unit of analysis in this study has changed as a result of the degree of internal structure that exists between the letters. The nine letters are analyzed as three words.

This argument could be applied to memory span experiments since the same unit is not being analyzed in all circumstances. The chunking and grouping strategies that may be employed by subjects, results in a change in the unit of analysis. Conclusions based on these findings do not lend much to the memory literature. The back memory paradigm, however, can secure the unit of analysis. Movements, if grouped or chunked, would prove to be detrimental rather than helpful. The procedure of presenting a new movement while recalling a separate movement would result in a complete change in the chunk or group on each separate presentation. This does not seem to be an advantageous strategy for this experimental manipulation. Each individual functional unit (i.e. a movement) is asked to be reproduced while manipulating load (the unit of analysis). Since the functional unit remains the same, no corresponding shift in the unit of analysis will occur.