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Separating visual features from tracked objects

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SEPARATING VISUAL FEATURES
FROM TRACKED OBJECTS

Thesis

Submitted to

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In Partial Fulfillment of the Requirements for

The Degree

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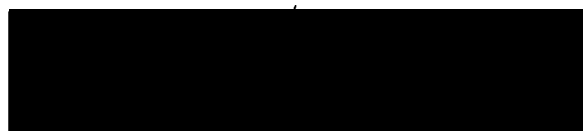
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August 2009

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2009

ABSTRACT

SEPARATING VISUAL FEATURES FROM TRACKED OBJECTS

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Visual short-term memory (VSTM) and attentional tracking are the essential processes involved in tracking multiple objects amidst distracters (MOT) and recalling object features. Previous research has found a deficit in performance accuracy thought to be due to interference between the VSTM and MOT tasks. In order to determine how process resource sharing could be the basis for the interference, the present research attempted to dissociate the VSTM stimulus from objects during tracking. Thus, in a separating-features condition, participants tracked objects that replicated themselves midway through a motion sequence while, concurrently, remembering the color of the original objects. Performance on the MOT task suffered more than on the VSTM task in the dual-task, separating-features condition, as compared with trials where only MOT or VSTM was tested. Comparisons with performance in single-task conditions indicate that the appearance of additional distracters in the separating-objects condition produces shared-resource deficits that primarily affect attentional tracking.

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TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
LIST OF FIGURES.....	vii
CHAPTER	
I. INTRODUCTION.....	1
Effects on capacity limits in tracking.....	3
Capacity limits for visual short term memory.....	5
Shared capacity and potential for separation of tasks in the present experiment...	7
The present research.....	7
II. METHOD.....	9
Participants.....	9
Apparatus and Stimuli.....	9
Procedure.....	10
Same-objects condition.....	10
Different-objects condition.....	15
Separating-features condition.....	16
III. RESULTS.....	20
Observed versus expected <i>K</i> -values.....	22
Analyses of dual-task conditions.....	27
Analyses of single-task conditions.....	28

IV. DISCUSSION.....	30
The cost of separating memory features from tracked objects.....	32
The cost to attentional tracking when separating features from tracked objects...	34
Directions for future research.....	36
Conclusions.....	38
REFERENCES.....	39

LIST OF FIGURES

Figure 1.	Design schematic for the Same-Objects (top) and the Different-Objects (bottom) conditions.....	12
Figure 2.	Design schematic for the separating-features condition.....	17
Figure 3.	All <i>K</i> -values (Combined and Individual) for Observed and Expected.....	21
Figure 4.	Combined <i>K</i> -values.....	23
Figure 5.	<i>K</i> -values for each task.....	25

CHAPTER I

INTRODUCTION

Why do moving objects demand a greater amount of attention than non-moving objects (Kerzel & Ziegler, 2005)? For example, the task of trying to identify and locate a specific car in a crowded parking lot is simple enough when the cars are stationary, but becomes much more difficult when all the vehicles are in motion. Typically each object (i.e., a car) being tracked possesses features that make that particular object unique from other objects in its vicinity. Tracking the object is often a primary concern for the individual, but it may also be necessary to remember each object's unique features. In some instances, an object may disassociate itself from some feature and we must remember the location of the feature and with what object that feature had been associated. For example, a person walks into a restaurant and removes his coat, then leaves the restaurant, forgetting the coat. The object-- in this case, a person --does not become different, but rather changes its outward appearance and leaves an identifiable characteristic behind-- the coat. Does tracking the object-- the man --become more difficult because the characteristic of the coat is no longer a part of the object? The process of attentional tracking and the construct of visual short-term memory (VSTM) are the cognitive essentials necessary to perform a task of this nature. Previous research (e.g., Fougny & Marois, 2006) has found a deficit in performance accuracy when simultaneously performing a tracking and a VSTM task. This deficit is further enhanced when these tasks are conducted simultaneously and each task focuses on different objects

(Ko & Seiffert, 2006). Some researchers (e.g., Fournie & Marois) attribute the deficit to interference between VSTM and tracking because they share a cognitive process such as attention (Cavanagh & Alvarez, 2005). However, the intent of the previous research (e.g., Fournie & Marois; Ko & Seiffert) was to examine the maintenance of memory for the features of the tracked objects, rather than the separation of VSTM and tracking such that the extent of shared attention can be determined. So, what happens when a feature of the tracked object is removed while it is in motion? The present research set out to discover if “feature dissociation” amidst the tracking sequence imposes a greater attentional load and a reduced attentional capacity as compared to when the feature and object are associated throughout the task. In other words, does feature dissociation reduce the combined capacity for attention and memory, such that performance accuracy is lower than when features and associated tracked objects are simultaneously encoded and maintained in memory? If so, simultaneous encoding produces a single unitary representation - what is called an object-based representation (Olson & Jiang, 2002).

Dissociations that distinguish between memory processes (Jacoby, 1991; Roediger, 1990; Toth, Reingold, & Jacoby, 1994), systems, (Reber, 2002; Schacter, 1990; Tulving, 1987) functional types like visual and spatial memory (Darling, Sala, & Logie, 2007), and between components of other cognitive systems, such as that between object identity and object location in perception (Logie, 2003) are well established. However, there is no empirical evidence for dissociation between VSTM for features and the perception of the locations of a moving object in a visuo-spatial tracking task. Further, it is logical to assume that tracking more than one object makes an even greater demand on attentional resources (Pylyshn & Storm, 1988). That is, tracking a larger

number of objects or features should cause a reduction in performance accuracy (Pylyshn & Storm, 1988; Yantis, 1992; Scholl, Pylyshn & Feldman, 2001). Thus, while various sources of evidence support the idea that the activity of different cognitive systems and processes can be segregated, the present research is a new effort to isolate the components of the interaction between VSTM and several independently moving targets as they draw on attention.

Effects on capacity limits in tracking

Pylyshyn and Storm (1988) documented the ability of participants to monitor several simultaneously moving objects effectively. The multiple-object tracking (MOT) task requires individuals to track a set of identical targets that are moving amidst a group of distracters in random motion within a display. Researchers (e.g., Pylyshyn & Storm, 1988; Yantis, 1992; Alvarez & Cavanagh, 2005) have found that participants are able to track reliably approximately four objects, and that a greater number of objects to be tracked results in a decrease in performance accuracy. Although there are a variety of opinions regarding what types of mechanisms underlie the tracking phenomenon (see Cavanagh & Alvarez, 2005, for discussion), it is widely accepted that attention plays a major role, thus the term “attentional” tracking is used (Alvarez & Cavanagh, 2005).

One of these opinions is based on mounting evidence for an advantage to performance of a concept called the object-based mechanism (Yantis, 1992) in the tracking paradigm. That is, object representations play a key role in tracking, beyond the influence of the object’s spatial location. Yantis’ study supports the object-based mechanism over other explanations (e.g., multiple resource theories; Olson & Jiang, 2002) by showing that participants demonstrate an improved ability for tracking when the

strategy of using an imagined polygon, mentally superimposed to create a single object from the tracked targets, is incorporated. Thus, in this case, the object-based mechanism strategy involves creating an object representation—the imagined polygon—as a vehicle for grouping the targets, while continually updating the representation as the targets at the polygon's vertices move about the display. Analogous to the concept of chunking in memory (Miller, 1965), this idea of grouping multiple items together has been shown to improve performance accuracy.

Along with spatial layout, visual properties (e.g., speed, shape, proximity) of the tracked objects also have an influence on the attentional demands of the task. One example is the importance of the center of an object as a feature. Scholl, Pylyshyn, and Feldman (2001) had observers track a target that was a single end-point of a line. The connecting line between the tracked end-point and the non-tracked end-point caused a severe decrease in tracking performance as compared with that for targets that were not connected (e.g., dots). One explanation for these results is that although participants were instructed to avoid focusing on the center of the line and focus on the target (the end-point), the tendency to do the opposite persisted. That is, people migrated visually to the center of a tracked object and any attachments (Scholl et al.). Consistent with this finding, Alvarez and Scholl (2006) found that a central focus on a target was important for effective attentional tracking. They required participants to detect flashing probes on a region of moving lines in a tracking task. Results showed that when probes were located at the center of the tracked object—in this case, a line—probe detection was more likely than when probes were located away from the center—towards the end-points of the line. Likewise, other research (van Marle & Scholl, 2003) on this tendency to focus on the

center of a target for the MOT paradigm indicated a decrease in tracking ability if objects are moving without fixed features (i.e., a center) while transitioning from one spatial location and shape to another location and shape in a display (e.g., a dot morphs into a triangle) and not having a defined identifiable center. In other research, Van Marle and Scholl used a stimulus that manipulated both the expansion and reduction in the size of some objects during a tracking task. To accomplish this, the center was necessarily enlarged and reduced. Results of this study showed that there was impairment in attentional tracking when objects did not have a constant, salient center; whereas, performance accuracy was greater when a constant center was represented. Thus, visual characteristics of an object, such as its center, location, as well as the number of objects being tracked, seem to determine the capacity and selectivity of attention when tracking.

Capacity limits for visual short-term memory

VSTM is the encoding, retention, and retrieval of visual information, for a limited set of objects that has been retained for a brief period of time (Miller, 1956). There are differing opinions about retention and retrieval in relation to this limit on capacity in VSTM (Luck & Vogel, 1997; Lee & Chun, 2001). However, Luck and Vogel propose that VSTM utilizes an object-based mechanism for memory, regardless of the number of features presented by the object. That is, objects are represented in VSTM as a set of integrated features. To examine their hypothesis, Luck and Vogel asked participants to remember the locations of objects with two features – color and shape – for brief intervals of time. They determined that the capacity limit of VSTM for location of a number of colored squares was approximately four objects, with memory performance declining with exposure to a larger set of colored squares. Subsequent studies (e.g.,

Vogel, Woodman, & Luck, 2001) replicated these findings, supporting a consistent capacity limit of four objects in VSTM, a number significantly less than that of the approximate capacity of seven that many researchers since Miller (1956) had believed.

Other researchers' (e.g., Lee & Chun, 2001) concerns about Luck and Vogel's (1997) results focused on the spatial location properties of the task that had been used. The speculation was that their results may not have been due to the use of features associated with the VSTM task, but rather due to memory for spatial locations. These VSTM properties were investigated by Lee and Chun by utilizing a set of overlapping stimuli that allowed them to manipulate features as well as spatial location, similar to a procedure previously used by Duncan (1984). Lee and Chun controlled the spatial location disparity of objects by allowing two objects to occupy the same spatial location. The results demonstrated that, as Luck and Vogel had described, VSTM retains and reproduces objects as a set of integrated features and, at the same time, these results ruled out the possibility that spatial location plays a critical role in object memory. These studies identify the capacity limits for VSTM while allowing for effective retrieval of objects, if encoded and retrieved as a grouped set of features, with the exception of location as one of those features.

VSTM for both color and shape as features has also been attributed to a process utilizing multiple resources (Navon & Gopher, 1979; Olson & Jiang, 2002; Wheeler & Treisman, 2002). These resources are directed toward processing varying types of features (color, shape, orientation, etc.) that may be present in an object. However, these features seem to affect capacity in distinct ways and may not necessarily be sharing VSTM capacity due to a common dimension like shape or color (Olson & Jiang). Olson

and Jiang were unable to replicate the findings of Luck and Vogel (1997), and tested other properties of the object-based mechanism. Their results demonstrated an improvement in VSTM accuracy when objects contained features distinct from other objects (e.g., shape or color). On the other hand, Olson and Jiang found that accuracy reached its apex when two distinct features were placed onto the same object (e.g., shape and color). This finding indicates that VSTM capacity is partially determined by the number of features that are required to be stored, but multiple features can also be stored relatively effectively if integrated by the object-based mechanism.

Shared capacity and potential for separation of tasks in the present experiment

Fougnie and Marois (2006) found poorer performance when tracking and memory tasks are concurrent and involve different objects. This finding appears to demonstrate shared resources between attention and memory with a shared cognitive process. Ko and Seiffert (2006), using a modification of Fougnie and Marois' dual-task procedure, found that concurrent deployment of VSTM and attentional tracking is efficient when the tasks involved the same object (e.g., memorizing a feature of an object that the participant was asked to track). This suggests a common object representation for the two cognitive functions. Ko and Seiffert explained their findings with object-file theory (Kahneman, Treisman & Gibbs, 1992). This theory states that the memory for an object is maintained as a history of features so that the identity of the object (a sum of the features) is permanent despite dynamic changes.

The Present Research

The present study attempted to replicate the findings of Ko and Seiffert (2006), using similar stimuli and methods, while further investigating potential interference

between tracking and memory in their use of attention. This experiment incorporated a condition designed to distinguish between VSTM and the attentional demands of MOT while objects were being tracked. In order to achieve this, there was a memory task in which a feature – color – was removed from tracked objects during a motion sequence. Participants tracked objects among distracters and later remembered whether one of the objects had originally been presented in color at the beginning of the tracking task. The hypothesis was, then, that tracking and memory compete for attentional resources, and, thus, there would be a greater decrement in performance accuracy in this type of concurrent memory and tracking task. In contrast, performance accuracy would improve in the conditions where the color of the objects was maintained throughout the duration of the tracking task. Alternatively, if the interference between tracking and memory was reduced by removing the to-be-remembered color from the tracked objects, performance accuracy would improve. This finding would indicate that the encoding and maintenance of objects using an object-based mechanism would be the explanation, more than attentional tracking, for the decrement in performance.

CHAPTER II

METHOD

Participants

Participants were 15 students (13 undergraduate and 2 graduate) enrolled at the University of Dayton, a private, medium-sized Midwestern institution. Participants were recruited from students who were given the opportunity to volunteer for lab research credit in the spring of 2009. The mean age was 21.27 years ($SD = 1.33$ years), with 11 female participants and 4 male participants. Participants engaged in the research in return for a pizza party and according to the standards and rules established by the American Psychological Association (APA, 2002) and the Research Review and Ethics Committee of the Psychology Department, at the University of Dayton. All participants' names were kept separate from their data, and their identity remained confidential.

Apparatus and Stimuli

The experiment was presented with MATLAB using the Psychophysics Toolbox extension (Brainerd, 1997; Pelli, 1997) and administered on a MacBook Pro (2.2 GHz Intel Core 2 Duo) utilizing the DVI external video output to display the stimuli on an adjacent CRT Sony Trinitron Multiscan 200SX monitor, with a screen size of 32 cm x 24 cm. The visual display was a black background with a white frame in the shape of a box in the center of the screen to define the tracking area. Colors used for the VSTM task were selected according to their discriminability from each other. The respective RGB values [R G B] for each color used were for red [200 0 0], green [0 200 0], blue [0 0 200],

purple [150 0 150], brown [117 85 40], orange [255 128 0], dark green [0 125 50], and buff [255 215 0].

Procedure

Data were collected in a 1.5 m x 2 m testing room with an individual participant seated approximately 50 cm away from the display apparatus, and subtending a 32° visual angle, under light conditions using only the display illumination; a photometer (Minolta Luminance Meter 1, AMRL 6570) measured the amount of illumination from the display monitor to be approximately 18 lumens. There were three primary conditions used in this experiment: same-objects, different-objects, and separating-objects. In each of these conditions, participants were instructed to remember colors for a VSTM task and to keep track of several targets in the MOT task and, unless otherwise noted prior to each trial, a participant was expected to perform each task exclusively. Each trial within these conditions consisted of four stages: suppression, encoding, tracking, and response collection.

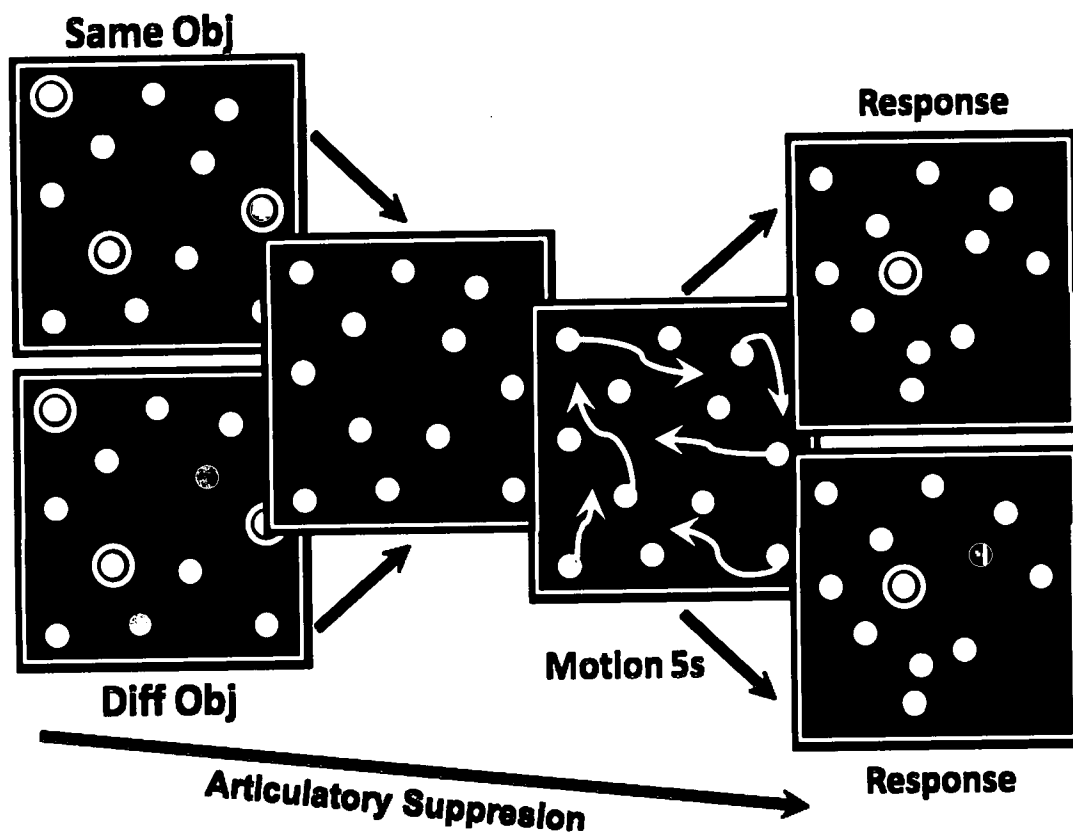
1. *Same-Objects Condition.* Participants were informed prior to the start of each trial whether or not the subsequent trial was a single-task trial. For single-task trials, participants performed only the MOT task. It was not possible to have a single-task situation for the VSTM task in this same-objects condition because the focus of the VSTM task - the color - was directly linked to the tracking task.

At the start of each trial in this condition, participants began the *suppression stage* of the trial. This stage was used to produce an articulatory suppression to inhibit the participant from rehearsing the VSTM colors during

the encoding and tracking tasks. Two different, randomly-generated, white, single-digit numbers written in Arial, 24 pt font, with pronunciation being only one syllable, were presented simultaneously, in a vertical arrangement, at the center of the tracking area. The participant was instructed to say the two digits out loud, at approximately two digits per s throughout the duration of the trial, until the response collection stage began. Digits for the suppression task were displayed on the monitor for 1500 ms. After this time, the two digits were removed from the screen, and the participant was instructed to continue saying the two digits for the duration of the trial. In addition, a repetition-threshold detection mechanism from the internal microphone in the computer was used to indicate adequate articulation. If adequate articulation threshold was not achieved during a trial, a warning screen would appear prior to the subsequent trial asking the observer to speak louder or faster for the articulatory suppression.

A schematic demonstrating the remainder of the trial can be found in Figure 1. After the digits used for the suppression stage disappeared, 12 stationary dots were presented on the screen within the tracking area. This indicated the start of the *encoding* stage of the trial. Each dot subtended an approximately 1.25° visual angle within the tracking area. The starting location of each of the dots was determined by dividing the tracking area into a 4 x 4 grid with each dot assigned randomly to a pair of grid coordinates (x,y) that corresponded to computer monitor pixel locations within that grid location. A dot was placed randomly, both horizontally and vertically, within

Figure 1: Design schematic for the Same-Objects (top) and the Different-Objects (bottom) conditions.



Either both dual-task (MOT and VSTM) or single-task (MOT or VSTM) cues were presented at the start of the trial and lasted for 5 s. Afterwards, cues were removed and the conditions looked identical, as all dots turned white and motion began. After 5 s of motion, all of the dots stopped, and participants were probed simultaneously for a MOT and VSTM judgment. Responses were collected individually with response order counterbalanced by block for each participant to prevent response bias. Articulatory suppression was conducted from the onset of the task cues until the response screen appeared.

the parameters of that grid location. The dots were either white or colored at the start of a given trial. For each trial in this condition, three target dots were each a unique color selected from the colors for the VSTM task. Each of these dots was cued with a white, surrounding circle indicating it as a target for the MOT task. The remaining nine dots were white. The encoding stage lasted for 5 s.

Following the encoding stage, the three colored dots turned white, and the cue circles were removed. These changes indicated to the participant that the *motion stage* was about to commence. In this condition, the three target dots, which were colored at encoding, moved about the screen amidst three other moving white distracter dots. The remaining six dots were stationary throughout the duration of the motion stage. The initial trajectory direction for the motion of each moving dot was randomly selected from between 0° and 360° with a movement size of approximately five pixels for each refresh (60 Hz) of the monitor. The solitary constraint on determination of these distance steps in the movement sequence was that an individual dot only moved randomly between -20° and $+20^\circ$ from the previous trajectory to prevent sudden jumps in the movement. When a dot was within 20 pixels of the edge of the tracking area it was repulsed; that is, its motion was set perpendicular to that corresponding edge (+ or - 20° , at the speed of the steps). When a dot was within 30 pixels of a corner in the tracking area its motion was shifted to the bisection of the right angle at the corner. A similar repulsion component was used between the dots, themselves, in order to prevent occlusion of one dot by

another. This repulsion was scaled with increasing intensity as dots gained in proximity to one another. These repulsion factors produced variability in the trajectories and speed (approximately 10° of visual angle per s) of each dot. The average velocity of each dot was approximately 9° of visual angle per second. The motion stage lasted 5s.

Upon the completion of the motion stage of each trial, the *response collection* stage began. Two responses, indicating VSTM and MOT, were probed and recorded by keystrokes on the keypad at the end of each trial. A target selected for the VSTM probe was never the same target as that selected for the MOT probe. During the VSTM probe, all dots remained stationary while color was re-applied to one of the targets. A valid probe occurred when the target dot appeared in the same color as it did at encoding. An invalid probe occurred when the VSTM target dot appeared in one of the two colors that had been presented on the other target dots at encoding. An equal number of valid and invalid probes were used within each block. Participants indicated whether the color of the VSTM target dot was the same or different than it was at encoding by pressing either the 1, "same", or 2, "different", key on the computer keyboard. There was a delay of 250 ms between the response to the VSTM probe and the onset of the MOT probe, during which the VSTM target remained on the display. For the MOT probe, a white, cuing circle appeared around one target or distracter dot equally often. Valid probes appeared on tracked targets and invalid probes appear on distracters, all of which were previously in motion. Participants indicated whether the circled dot was one of

the tracked targets by selecting either the 4, “yes”, or 5, “no”, key on the keypad. The designated response keys were the only available key presses that could advance a trial. After the response to the MOT probe, a blank, black screen appeared for 500 ms before the next trial. The order for VSTM probe and MOT probe alternated between blocks of trials for each participant, in order to prevent response-order bias. If a single task was indicated at the start of the trial, a “dummy” response was used in place of the VSTM response in order to progress the trial. These “dummy” responses were simply key presses to advance the trial and were discarded when the experiment was completed.

2. *Different-Objects Condition.* Participants were informed prior to the start of each trial whether or not the subsequent trial was a single-task trial. For single-task trials, participants performed either the MOT task or the VSTM task, only.

The *suppression stage* in this condition was identical to the suppression stage described for the same-objects condition.

A schematic demonstrating the remainder of the trial can be found in Figure 1. After the digits used for the suppression stage disappeared, 12 stationary dots were presented on the screen within the tracking area. This indicated the start of the *encoding* stage of the trial. The same placement and display parameters described in the same-objects condition were used for this condition. For each trial in the different-objects condition, three dots appeared, each in a unique color selected from the colors for the VSTM task. Three different dots were cued with white circles indicating them as targets

for the MOT task. The remaining six dots were stationary and white. The encoding stage lasted for 5 s.

Following the encoding stage, all colored and target dots turned white and the cue circles were removed. This indicated to the participant that the *motion stage* was about to commence. In this condition the three target dots moved about the screen amidst three moving, distracter dots. The previously-colored dots whose color information the subject had been asked to remember were static on the screen while the remaining three dots remained stationary throughout the duration of the motion sequence. The motion parameters described in the same-objects condition were used in this different-objects condition. The motion stage lasted 5 s.

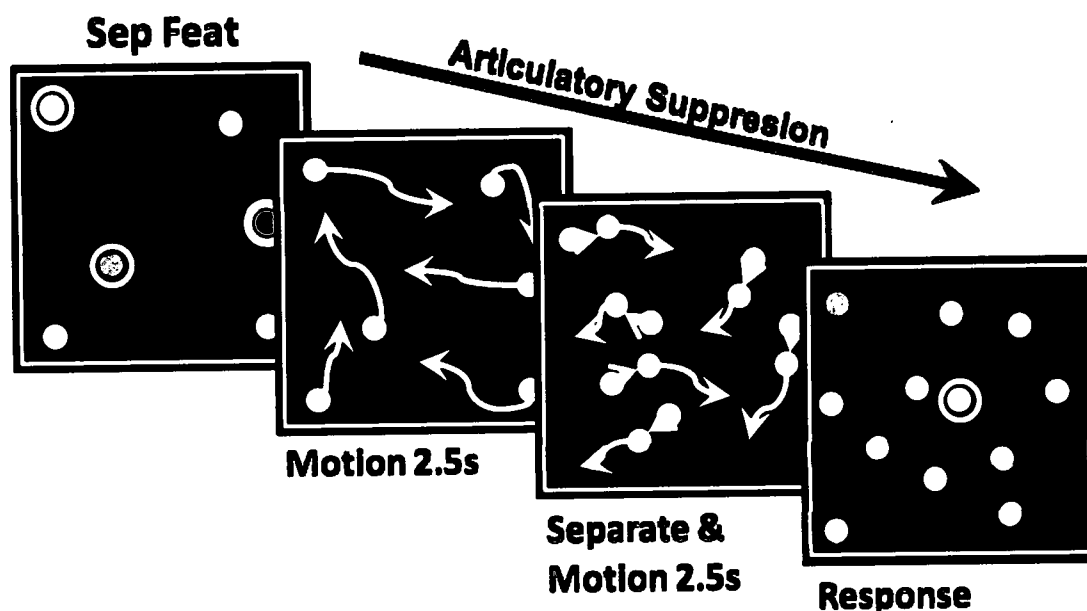
The *response stage* was identical to that described for the same-objects condition except that single-task trials could now also include the VSTM task.

3. *Separating-Features Condition*. Participants were informed prior to the start of each trial whether or not the subsequent trial was a single-task trial. For single-task trials, participants performed either the MOT task or the VSTM task, only.

The *suppression stage* in this condition was identical to the suppression stage described for the same-objects and different-objects conditions.

A schematic demonstrating the remainder of the trial can be found in Figure 2. After the digits used for the suppression stage disappeared, six stationary dots were presented on the screen within the tracking area. This indicated the start of the *encoding* stage of the trial. The same placement and

Figure 2: Design schematic for the separating-features condition



Either both dual-task (MOT and VSTM) or single-task (MOT or VSTM) were presented at the start of the trial and lasted for 5 s. Afterwards, all dots turned white and motion began. After 2.5 s of motion, a tone would sound, and the dots would separate and leave stationary counterparts behind. Participants were informed that the color information previously associated with a moving dot was to be remembered on the newly-created stationary dot. Motion would then continue for non-stationary counterparts for 2.5 s. After the motion sequence ended, all of the dots stopped, and participants were probed simultaneously for a MOT and VSTM judgment. Responses were collected individually with response order counterbalanced by block for each participant to prevent response bias. Articulatory suppression was conducted from the onset of cues until the response screen.

display parameters described for the previous conditions were used for this condition. For each trial in this condition, each of three target dots was a unique color selected from the colors for the VSTM task. Each of these dots was cued with a white, surrounding circle indicating it as a target for the MOT task. The remaining three dots were white. The encoding stage lasted for 5 s.

Following the encoding stage, all colored and target dots turned white and the cue circles were removed. This indicated to the participant that the *motion stage* was about to commence. In this condition the three target dots, which linked with the colors used in the VSTM task, moved about the screen amidst three moving, distracter dots. The same motion parameters described in the previous conditions were used in this condition except that at the midpoint of the motion sequence, a tone sounded, and an additional dot appeared on the screen where each of the dots in motion had been located just prior to the tone. Thus, the number of dots on the display increased from 6 to 12. The newly-created dots remained stationary among their moving counterparts. In addition, participants were informed that the color information previously associated with the moving dots should be remembered on the newly-created stationary dots. The motion stage lasted 5 s.

The *response stage* was identical to that described for the different-objects condition.

In all conditions, there were an equal number of valid and invalid probes for both the VSTM and MOT tasks. Trials consisting of the crossings of condition (same-objects, different-objects, separating-features) and type of task (VSTM single, MOT single, dual),

with four repetitions of each type of trial, totaled 32 different types of trials. (No VSTM single task could be performed for the same-object condition.) There were five blocks of trials, and all trials were randomly ordered within a block. Thus, each block contained an equal number of all trial types, four each, equaling 32 trials per block, and 160 trials for the experiment. Participants engaged in five practice trials prior to the start of the experiment in order to familiarize themselves with the task. In addition, at the end of each block, participants were shown their overall mean performance accuracy for the VSTM and MOT tasks to inform them of their progress in the experiment and to encourage them to perform well on the tasks. Completion time for the entire experiment was approximately 1 hour.

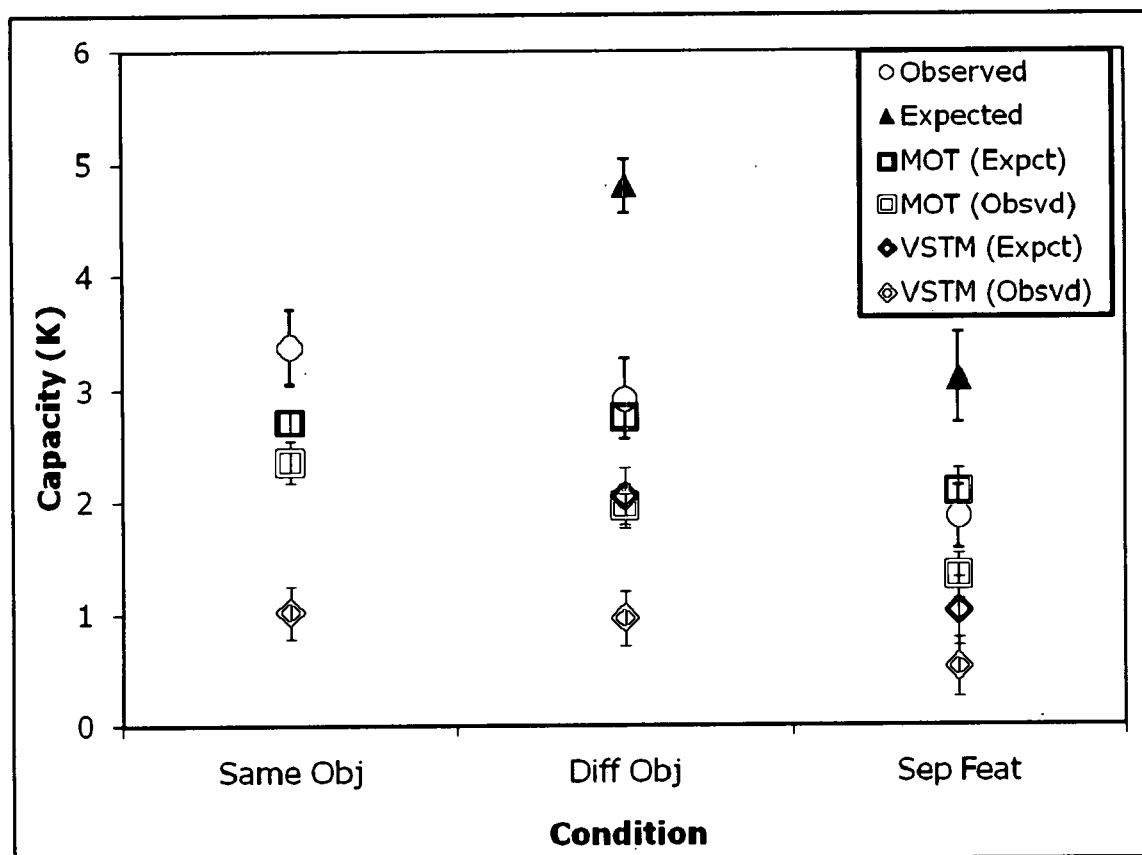
CHAPTER III

RESULTS

The dependent variables of interest in this research are the accuracy performance for the MOT and VSTM tasks. Monitoring of articulation was performed to insure that verbal rehearsal was not used for the VSTM task. All participants were monitored for articulations during the tasks from the beginning of each trial until the response probes were presented. The maximum number of articulation counts that could be recorded was 45, with a minimum count of 25 before the warning system would activate. A mean number of articulations was calculated from the audio recording device within the computer. Mean articulation performance for all participants was 39.35 articulations ($SD = 2.47$). No participant was within 2 SD s of the minimum count warning threshold for the experiment. Furthermore, no single trial was below adequate performance (3 syllables per s, for a total of 15 articulations for a 5-sec articulation period), which would warrant the removal of that trial from the experiment. It should be noted that these articulation counts were observed merely as an indication that adequate suppression was performed by all participants during the task, and they do not warrant further analysis.

The complete results of the present research are displayed in Figure 3; represented are K -values for performance on single-task trials, K -values for performance on dual-task trials, a combination of K -values for MOT and VSTM performance for the dual-task trials (i.e. *observed*), and a combination of K -values for MOT and VSTM performance for single-task trials (i.e. *expected*). K -values are the result of a

Figure 3: All K-values (Combined and Individual) for Observed and Expected



Observed versus expected performance accuracy for both tasks combined or represented individually. Participants performed a VSTM and a MOT task independently (single task) as well as concurrently (dual task). Observed K is the sum of the MOT and VSTM task under dual-task manipulations or as each task represented individually. Expected K is the sum of the MOT and VSTM task under single-task manipulations or as each task represented individually.

transformational method used to estimate the capacity of attention and memory (cf., Fougne & Marois, 2006; Ko & Seiffert, 2006); thus, Cowan's (2001) K -formula was used to convert accuracy raw data to capacity estimates of memory and attention. The use of this formula is common, and recent in the tracking literature (Bettencourt & Somers, 2009). The formula is written as:

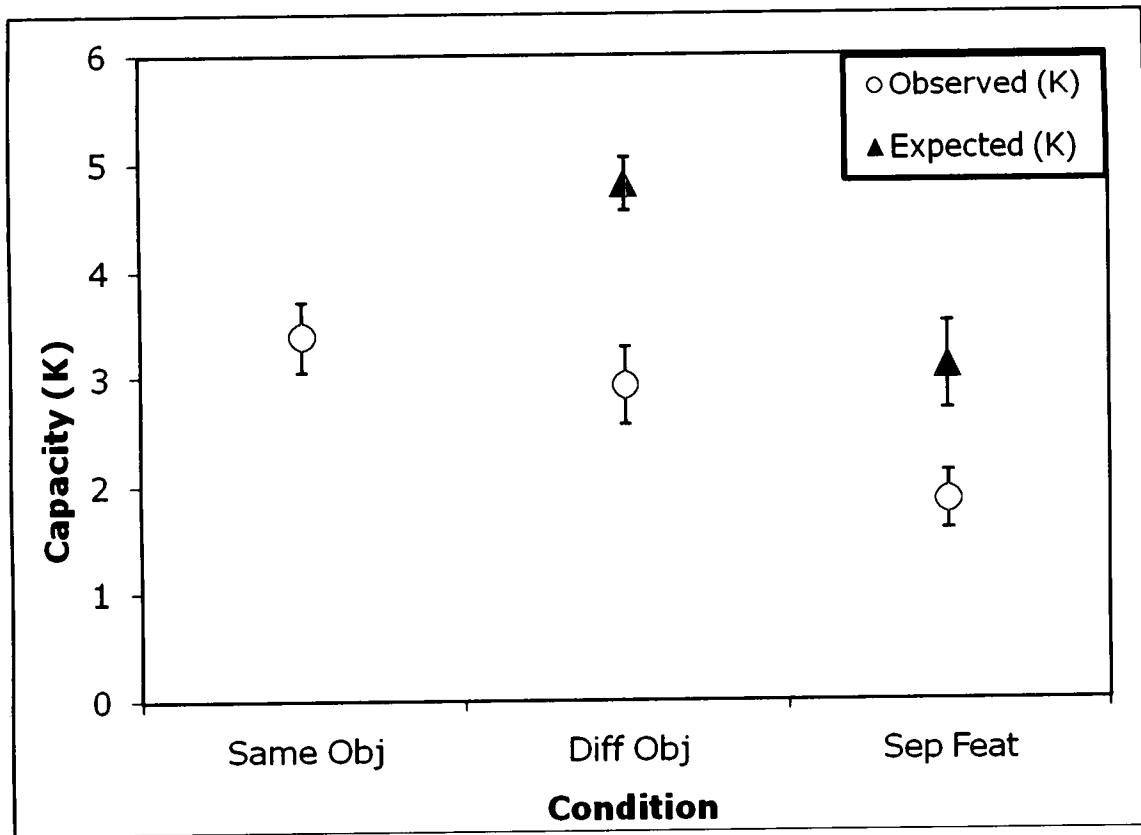
$$K = [h + r - 1] \times n$$

where K is the estimated number of items maintained by each cognitive operation, h is the proportion of hits (correct identification of a probed target), r is the proportion of correct rejections (correct identification of a probed distracter), and n is the number of items targeted for memory storage or attentional tracking for each trial. In the present experiment, n equals 3, as this was the total number of items used for both VSTM and MOT tasks. Analyses of these data are reported in this order: observed versus expected K -values, untransformed proportions for single-task performance, and untransformed proportions for dual-task performance.

Observed versus expected K -values

Figure 4 represents the combination of MOT and VSTM performance accuracy for both the dual-task (observed) and single-task (expected) trials. Of primary interest in Figure 4 is that expected K -values are greater than observed K -values (respectively, as reported) for both the different-objects ($M = 4.80$, $SD = 0.97$; $M = 2.92$, $SD = 1.38$) and separating-features conditions ($M = 3.10$, $SD = 1.54$; $M = 1.85$, $SD = 1.07$). It should be noted that single-task conditions allowed for the evaluation of the maximum capacity for a particular task, VSTM or MOT. A maximum expected capacity for both tasks is the sum of the maximum possible capacities for the single-task conditions, as this would

Figure 4: Combined *K*-values

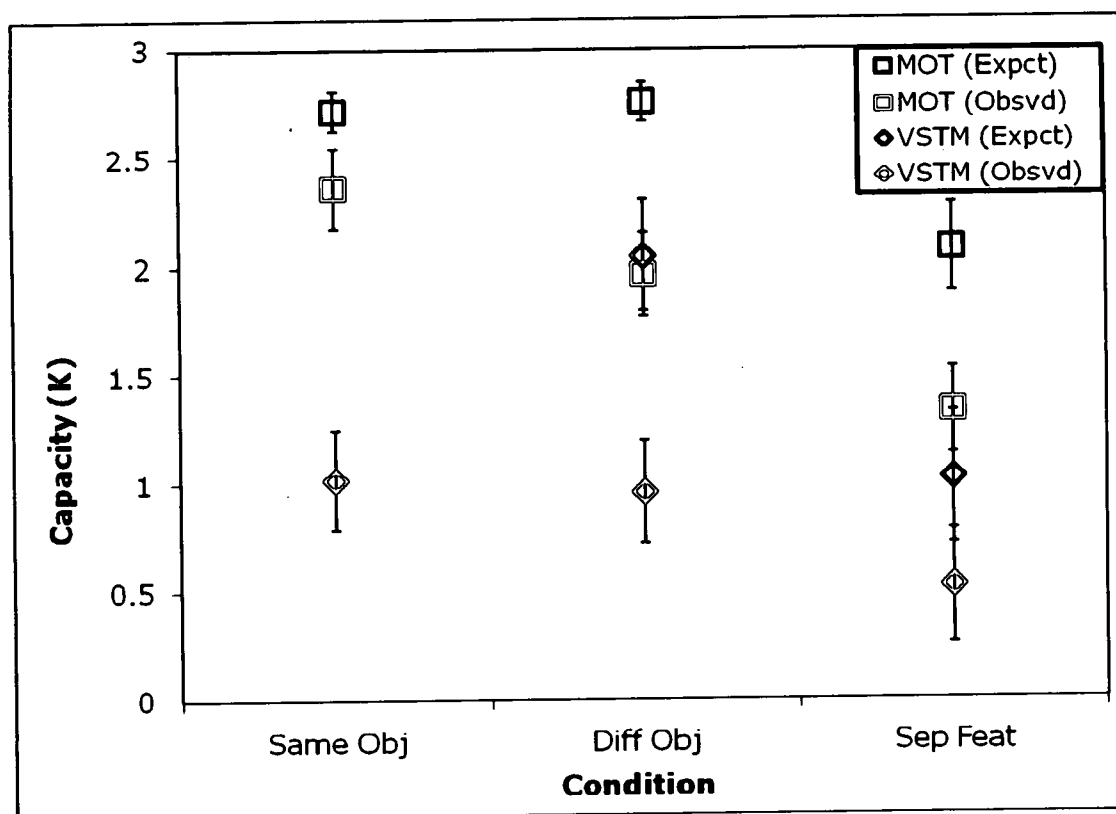


Observed versus expected performance combined (MOT and VSTM). Participants performed a VSTM and a MOT task independently (single task) as well as concurrently (dual task). Observed *K* is the sum of the MOT and VSTM task under dual-task manipulations. Expected *K* is the sum of the MOT and VSTM task under single-task manipulations.

indicate no reduction in performance due to the absence of an interaction between memory and attentional processes. In the present experiment, 3 (three colored dots or three tracked dots) is the maximum possible capacity for each single task, VSTM or MOT, while the maximum combined capacity is 6, VSTM plus MOT. The observed dual-task performance was the combined K -values for the MOT and VSTM performance. The difference between the expected and observed K -values reflects the degree to which attentional tracking and memory have dual task costs; consequently lower values for the difference indicate optimal use of processing resources in the dual-task situation.

Performance accuracy for both the MOT and VSTM without combined scores is represented in Figure 5. An ANOVA could not be conducted due to the absence of a viable measure of single-task VSTM performance for the same-objects condition. Instead, five correlated groups t -tests were conducted comparing the observed K -value with the expected K -value for the two conditions (separating-features and different-objects) and two tasks (MOT and VSTM), and the same-objects condition for the MOT task. There were significant differences between observed ($M = 1.96$, $SD = 0.74$) and expected ($M = 2.76$, $SD = 0.36$) K -values for the different-objects MOT task, $t(14) = 5.62$, $p < .001$, $\omega^2 = .69$; the separating-features MOT task (observed K : $M = 1.33$, $SD = 0.76$; expected K : $M = 2.08$, $SD = 0.79$), $t(14) = 2.83$, $p = .014$, $\omega^2 = .36$; and the different-objects VSTM task (observed K : $M = 0.96$, $SD = 0.94$; expected K : $M = 2.04$, $SD = 0.98$), $t(14) = 4.97$, $p < .001$, $\omega^2 = .64$. There were no significant differences for the same-object MOT task (observed K : $M = 2.36$, $SD = 0.73$; expected K : $M = 2.72$, $SD = 0.37$), $t(14) = 1.94$, $p = .07$; and the separating-features VSTM task

Figure 5: K-values for each task



Observed versus expected task performance in each task (MOT or VSTM). Participants performed a VSTM and a MOT task independently (single task) as well as concurrently (dual task). Observed K is performance accuracy in either task under dual-task manipulations. Expected K is performance accuracy in either task under single-task manipulations.

(observed K : $M = 0.52$, $SD = 1.03$; expected K : $M = 1.02$, $SD = 1.18$), $t(14) = 1.29$, $p = .22$. The latter can be explained by the fact that the single-task, separating-features VSTM task required tracking for half of the trial duration; thus, half of each single-task trial is actually calling on the participant to perform both MOT and VSTM tasks, resulting in poorer performance. These results coincide with the findings of Fougny and Marois (2006), demonstrating that performance accuracy is better when MOT and VSTM tasks are performed independently, which indicates that there is a processing interaction between memory and attention that negatively affects performance.

Figure 4 adds additional support to this conclusion; the observed K -value for the separating-features condition ($M = 1.85$, $SD = 1.07$) is less than that for either the same- ($M = 3.38$, $SD = 1.26$) or different-objects ($M = 2.92$, $SD = 1.38$) conditions, although there does not appear to be much of a difference between the latter two conditions. A one-way, within-subjects ANOVA evaluated these differences. K -values were reliably different among conditions, $F(2, 28) = 8.76$, $p < .001$, $\omega^2 = .34$. As expected, planned comparison, correlated groups t -tests confirmed that performance in the separating-features condition was significantly less than that in the same-objects condition, $t(14) = 3.99$, $p = .001$, $\omega^2 = .53$; and the different-objects condition, $t(14) = 2.89$, $p = .012$, $\omega^2 = .37$. However, there was no significant difference in K -values between the same-objects and different-objects conditions, $t(14) = 1.23$, $p = .235$. Therefore, the key finding of Ko and Seiffert (that dual-task performance is better when the VSTM features are located on the tracked objects) was not replicated in the present results. These results, however, indicate that there is a larger dual-task performance penalty associated with separating the

VSTM features from the targets amidst the tracking sequence as compared to no separation.

Analyses of dual-task conditions

As can be seen in Figure 5, MOT dual-task performance appears to be better than VSTM dual-task performance in all conditions. To confirm this observation, a 2 (task: VSTM vs. MOT) x 3 (condition: same-objects, different-objects, separating-features) within-subjects ANOVA was conducted with the data collected from the dual-task conditions. Results demonstrated a main effect for condition, $F(2, 13) = 4.60, p = .042, \omega^2 = .11$; and task, $F(1, 29) = 34.15, p < .001, \omega^2 = .30$. However, there was no interaction between condition and task, $F(2, 28) = 0.72, p = .491$. Thus, performance on the VSTM task was consistently lower than that on the MOT task, for each condition.

Further analysis was conducted by performing a one-way within-subjects ANOVA to evaluate performance differences for each of the three conditions separately in both the MOT and VSTM tasks. There was a significant difference in observed MOT between the three condition means, $F(2, 28) = 8.64, p = .001, \omega^2 = .44$. A post hoc Tukey HSD test having a critical difference value of 0.61 showed that the observed separating-features MOT performance ($M = 1.33, SD = 0.76$) was significantly less than that in each of the observed same- ($M = 2.36, SD = 0.73$) and different-objects ($M = 1.96, SD = 0.74$) conditions, whereas the same- and different-objects conditions for observed MOT performance were not significantly different from each other. For the VSTM performance there was no reliable difference between the three conditions, $F(2, 28) = 2.44, p = .15$; VSTM performance was the same for the observed VSTM same-objects ($M = 1.02, SD =$

0.88), different-objects ($M = 0.96$, $SD = 0.94$), and separating-features ($M = 0.52$, $SD = 1.03$) conditions.

Analyses of single-task conditions

Figure 5 also shows that performance for single-task MOT was better than that for the single-task VSTM for all conditions. To verify this, a one-way within-subjects ANOVA evaluated performance for the expected MOT task for the three conditions. A significant difference was found between the three conditions, $F(2, 28) = 11.42$, $p < .001$, $\omega^2 = .38$. A post hoc Tukey HSD test having a critical difference of 0.39 showed that the expected separating-features MOT performance ($M = 2.08$, $SD = 0.79$) was significantly less than either the expected same- ($M = 2.72$, $SD = 0.37$) and different-objects ($M = 2.76$, $SD = 0.36$) conditions, whereas the same- and different-objects conditions for expected MOT performance were not significantly different from each other. These findings parallel the findings found for the observed MOT performance, however, the decrease in MOT performance accuracy for the expected separating-features condition is of concern because it indicates that the appearance of additional targets may lead to a decrease in performance.

Since there were no data collected to produce an expected value for the same-objects VSTM task, a one-way ANOVA was not conducted; instead, a correlated groups t -test evaluated differences in expected performance between the different-objects ($M = 2.05$, $SD = 0.98$) and the separating-features ($M = 1.02$, $SD = 1.18$) VSTM conditions. There was a significantly higher performance accuracy for the different-objects VSTM condition, $t(14) = 4.03$, $p = .001$, $\omega^2 = .54$. This result, as discussed earlier, could be explained by the fact that the single-task, separating-features VSTM task required

tracking for half of the trial duration; thus, half of each single-task trial is actually calling on the participant to perform both MOT and VSTM tasks resulting in poorer performance.

CHAPTER IV

DISCUSSION

The present research examined memory for features of tracked objects and the ability to retain the memory for those features when they are separated from the object being tracked during a tracking sequence. Previous research (e.g., Luck & Vogel, 1997; Scholl et al., 2001) have shown that both VSTM and attentional tracking, when studied in isolation, have object-based mechanisms, such that individual features of an object aide in both memory and tracking performance accuracy. Specifically, individual characteristics of an object (e.g., color, shape, location), for both VSTM and MOT tasks, seem to determine the efficiency with which each of these tasks is performed. Other findings (e.g., Ko & Seiffert, 2006) suggested an object-based advantage when pairing VSTM features with tracked objects, resulting in higher performance accuracy when the two tasks are conducted on the same object. That is, when a feature, such as color, is to be remembered for a tracked object, performance accuracy for both VSTM and MOT is greater when the feature is located on the same object compared to being on different objects. The present research investigated whether VSTM features could be effectively and efficiently separated from tracked objects, with the present results showing that this cannot be accomplished without an impact on performance. Specifically, dual-task performance suffers when an attempt to disassociate the MOT and VSTM tasks occurs within the motion sequence, as compared to when the two tasks are not disassociated and

the focal object contains the to-be-remembered features as well as being tracked for the duration of both tasks.

Attentional tracking and VSTM are two cognitive processes that have been studied extensively in isolation from each other (e.g., Pylyshn & Storm, 1988; Luck & Vogel, 1997). It has been suggested that the capacity-limited process that inhibits memory, may be attention (Cowan, 2001). This unique similarity in the use of attention and for the number of items held in both VSTM and MOT – four each– suggests the two tasks may rely on a common, capacity-limited process (e.g., Cowan, 1998; 2001). A possible competition between the two processes for cognitive resources warranted an investigation to discover whether there was a similarity in the cognitive properties of the two tasks (Fougnie & Marois, 2006). Previous results have shown that there is some but not complete overlap in the cognitive processes (memory and attention) used in VSTM and MOT (Fougnie & Marois, 2006; Ko & Seiffert, 2006). In the present research, we showed an overlap similar to that which had been demonstrated by the previous research. This conclusion was arrived at by comparing expected K -values (single task) with observed K -values (dual task); finding significant differences in performance for all conditions. The difference between these two capacities, expected and observed, demonstrates that some but not all cognitive resources are shared between the VSTM and MOT tasks. If cognitive processes were exclusive to either task, dual-task performance would have been identical to single-task performance, even when the two tasks were conducted simultaneously; another way of saying this is that, if there were no shared resources, the observed K -values in each condition would have shown no significant difference from the corresponding expected K -values.

The present experiment did not replicate the findings of Ko and Seiffert (2006), who showed better performance when VSTM features are on the same-objects as those being tracked, rather than on different objects. The results presented here, however, indicate that there is an even larger dual-task performance penalty associated with separating the VSTM features from the targets amidst the tracking sequence. This indicates that the use of cognitive processes to separate features into distinct objects amidst the tracking sequence hinders performance more severely than just maintaining objects, in memory, or for attentional tracking, over time.

The cost of separating memory features from tracked objects

Consistent with the findings of Fougner and Marois (2006) and Ko and Seiffert (2006), the present research showed that the accuracy performance of VSTM is significantly lower than the accuracy performance of the MOT task, in all conditions. This finding was also true for the separating-features condition, but, although the observed *K*-value was significantly lower for this condition, VSTM performance for the separating-features condition was not significantly different from that in either the same-object or different-object conditions. Of use in explaining the results is the work of Mitroff, Scholl, and Wynn (2004) who examined single objects that would split into two, in order to study object persistence. Mitroff et al. measured the response time to identify features of an object after the object had briefly moved along a linear trajectory across a computer monitor. The researchers used an object reviewing paradigm developed by Kahneman et al. (1992), which states that the memory for an object is maintained as a history of its features so that the identity of the object (a sum of the features) is permanent in the face of dynamic changes. Mitroff et al. cued a target object (a dot) with

an identifying feature (a letter), then removed the cues (the letter) and had the object move on a linear path. During the motion sequence the target object split, such that the target object divided into two objects (two dots) and re-displayed the identifying feature on only one of the dots. Meanwhile, a distracter object (a third, different dot) with its own identifying feature (a letter different from the target) would move in unison above or below the splitting target, but would not split along the course of its respective trajectory. The test for the participant was whether a dot labeled with one of the two features at the conclusion of the trial was correctly labeled or not. As a violation of Kahneman et al.'s rule, Mitroff et al. had the target object perform a split into two objects (two dots) and mislabeled a dot with the incongruent identifying feature (the letter associated with the distracter object that did not split) at the end of the motion sequence. Mitroff and colleagues found a slower response time for feature identification when the violation occurred, that is, when objects split and the identifying feature did not match the original on the target object. Rather than to VSTM, Mitroff et al. attribute their results to the use of an object-specific preview benefit, where an observer will associate the object file with its previously-cued location, rather than merely the maintenance and storage of the feature (the letter) with the object in memory (VSTM). They suggest two possible explanations for the apparent separation of a single-object file; one explanation attributes the separation to guessing and the other explanation attributes the separation to the notion that the feature is retained on both objects following the split.

The first explanation proposed by Mitroff et al. (2004) is that after a separation occurs, the participant merely guesses, meaning, for half of the trials the feature information would be associated with one of the newly-formed objects from the split, and

for the remaining half of the trials the feature information would be associated with the other object formed from the split. For the present experiment, this explanation seems unlikely, as Mitroff et al. did not inform participants with which of the two objects produced by the split they should associate the feature information. However, in the present experiment, color was used as the feature information, and participants were told specifically to associate that color with the stationary counterpart, and not the newly-created object, after the separation in the tracking sequence had occurred. Furthermore, if this first explanation is correct, the present results would have been a reduction in VSTM performance; that is, 50% of responses given by the participants would have been incorrect. In the present experiment, a K -value of zero would indicate chance performance, and as can be seen, performance was actually between .5 and 1 across all conditions.

Thus, the second explanation proposed by Mitroff et al. (2004) is, by default more appealing. They propose that at the time of the split, observers may actually maintain complete object file representations for both objects; that is, the feature information would be maintained in memory on both objects. For the present data, this second explanation is more consistent because actual performance (K) ranges between .5 and 1, corresponding to the probability of being correct 66% percent of the time. The object-specific preview benefit (where location of the original target is maintained in memory) can be identified as contributing to this enhanced probability of performance.

The cost to attentional tracking when separating features from tracked objects

The results of the present experiment are that there was a decrease in observed K -values when participants attempted to separate features from the tracked objects. For both

single-task and dual-task trials, performance on the MOT task was significantly lower for the separating-objects condition than that for the other two conditions. A possible explanation for this is that there was a general shift of attention to the stationary counterparts after the split and during the tracking sequence. On the other hand, Wolfe, Place and Horowitz (2007), using a modified MOT task, showed that there is no cost to performance when adding and subtracting individual targets from a tracked set of dots for an extended period of time, -even up to 10 min-, in their tracking task. Wolfe and colleagues had cued dots during the tracking sequence and instructed participants to add or remove these cued dots from the tracked set dependent on the cue presented, a red circle ("add") or the red letter "X" ("remove"). Furthermore, Ericson and Christensen (unpublished study, 2009) found that adding an additional target improved performance accuracy in MOT, although removing a single target from a tracked set of dots was more costly to performance accuracy. The present results demonstrate something somewhat different from those of Wolfe et al. and Ericson and Christensen; that is, there was a deficit in MOT performance when adding targets. However, this may be due to the design of the present research that called for three targets to be added simultaneously to the tracked set, bringing the total number of targets to six after separation. The previous designs (Wolfe et al.; Ericson & Christensen) are different in that they added only a single target at a time, bringing the total number of targets to four. This apparent limitation in the number of targets that can be tracked corresponds well with the original findings of Pylyshn and Storm (1988) which documented the ability to track approximately four objects at once, successfully. If we assume that participants code the stationary counterpart as a tracked target with the color representation in VSTM, there

was an increase in the tracked set, from three to six, thus, exceeding the limit of four cited in the attentional tracking literature.

The interpretation of this finding could be explained in part by the phenomenon previously discussed regarding separating the VSTM task (Mitroff et al., 2004). Pylyshn and Annan (2006) found that observers demonstrated a reduction in performance accuracy when performing a MOT task; they were instructed to ignore cued objects and track non-cued objects. The reduction in performance indicates that it is much more difficult to suppress items for tracking when given explicit cues to track. Much like previous findings (e.g. Wegner, Schneider, Carter & White, 1987; Pylyshn & Annan, 2003), in the present experiment, observers may have had difficulty ignoring the newly created stationary counterparts from the tracked set, and, thus maintained the color information with both objects, as was suggested by Mitroff et al. This inability to adequately ignore the newly created counterparts on the screen may explain why there is significantly lower performance for the MOT task in both the single- and dual-task trials for the separating-features conditions.

Directions for Future Research

Limitations of the present research and the separation paradigm warrant a look at several of these issues in future research. The first issue that would need resolution is the development of a valid evaluation of single-task VSTM performance in the separating-features condition. The presence of a tracking component with the VSTM task for the first half of the single-task VSTM trials renders this condition inadequate for assessing performance in the VSTM task, alone. One solution to this problem would be to include trials of variable length, in order to probe the participant for a response before and after

the separation occurs. This would enable the measurement of performance accuracy for the VSTM task at specific time points during a trial, most importantly just before and after the feature separation occurs.

The issue presented by the sudden addition of a large number of targets to the display should also be addressed, as seen by the significantly lower result for both the dual- and single-task MOT performance in the separating-features condition compared to the same- and different-objects conditions. The limitation for tracking is roughly four target items (Pylyshn & Storm, 1988) and the separating-features condition uses three items. However, it may be that after the separation occurs amidst the tracking sequence the newly formed dots are treated as tracked targets rather than as stationary objects with color information. If this is the case, we have increased the tracked set from three to six, which is well above the four-target limit. In order to support this speculation, a follow-up experiment that reduces the number of targets on the screen for the separating-features condition should be conducted to determine whether the reduction in performance is merely caused by the sudden onset of new targets, or rather the dual-task demands of the condition.

Finally, to compliment the arguments from Mitroff et al. (2004) regarding color features being allocated to both items after a separation occurs, an investigation should be conducted to examine both performance accuracy and reaction times for the dual-task, separating-features VSTM performance for both the stationary items and for the items continuing to be tracked. A simple expansion on the current separating-features condition could be conducted that probes VSTM either on one of the newly-created stationary items (as in the present experiment) or on one of the items that was to be continued being

tracked. In such a scenario, performance comparisons in VSTM accuracy and reaction time could be made between these different conditions. The results would then be assumed to explain what types of cognitive processing occur when the separation occurs in the tracking sequence; namely, the results would answer the question, "Is the memory information maintained for each of the objects that result from the separation process?" or, "Does the participant solely maintain the memory information for only one of the two objects (new and tracked, or original and stationary)."

Conclusions

The present research expands upon what was understood about the shared cognitive processes that exist between attention and memory. This competition for cognitive resources was previously shown based on retention in VSTM over the course of a MOT sequence (Fougnie & Marois, 2006). The results of the present study demonstrate that a further decrease in performance occurs when separating VSTM features from the tracked objects. However, this decrement in performance accuracy seems to be based solely on the MOT task. Future research should investigate several issues, most prominent among them being the need to implement a separation paradigm that controls for the sudden and simultaneous onset of multiple new sources of information.

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