HOW DO WE TRACK WHAT WE DON'T SEE?
SPATIOTEMPORAL INFORMATION IN MULTIPLE OBJECT TRACKING

by

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Abstract

Dynamic environments require us to visually track and maintain moving objects through space and across occlusions. The goal of the current research was to investigate the encoding and recovery of spatiotemporal elements in a multiple object tracking (MOT) paradigm. This research looked at the encoding and recovery of motion cues after occlusions to assess which spatiotemporal information is encoded, how this information is used during the occlusion, and which spatiotemporal elements impact the recovery of targets. Additionally, the impact of encoding specificity, or a lack thereof, between encoding and recovery was assessed for its impact on recovery.

Experiment 1 investigated the impact of having motion in both tracking and recovery phases of MOT. Motion facilitated recovery of targets that moved during the occlusion, highlighting the importance of motion encoding and the use of motion in recovery. Experiment 2 investigated the impact of having only direction information in the recovery phase on target recovery. Experiment 2 showed that direction information significantly improved performance in recovering targets that moved during the occlusion period. Experiment 3 examined location, direction, and motion information in both the tracking and recovery phase in order to determine the impact of having such information during tracking on recovery accuracy. The results of this experiment showed that the presence of spatiotemporal information in the tracking phase was required for accurate recovery of targets.

The findings of this thesis confirm that location information is a salient piece of information in MOT. The results suggest that direction information is also encoded in MOT. Traditional MOT paradigms may have failed to demonstrate the use of direction

cues because of the lack of encoding specify (or at least partial encoding specify) between the tracking and recovery phases. Overall, the theoretical contribution of this thesis is that target recovery after occlusion is facilitated by an off-line backward extrapolation. It is possible that stable spatiotemporal information such as direction information may be stored in long-term memory, while information that is dynamic and requires constant update, such as location-identity bindings, is stored in visual short-term memory.

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How Do We Track What We Don't See?

Spatiotemporal Information in Multiple Object Tracking

Until about a decade ago, research on perceptual and cognitive processing has been focused on static environments which has created a gap in our understanding of the construction and maintenance of dynamic environments. Given how frequently we monitor multiple objects and interact with dynamic environments, it is vital that we gain a better understanding of our cognitive and perceptual performance in the dynamic world in which we live. Seemingly our ability to construct and maintain dynamic environments is ingrained in our cognitive processes. Just consider the ease with which we maintain continuity in monitoring and tracking objects while navigating a busy sidewalk, playing sports, and even the skill needed to navigate our shopping cart around the grocery store. Accurate performance in dynamic environments such as air traffic control, military radar operations, and emergency response all require observers to continually update target locations in order to maintain up-to-date effective and safe execution of tasks. Empirical research has suggested that individuals are able to track the spatial locations of four to five dynamic objects at one time (Pylyshyn & Storm, 1988; Intriligator & Cavanagh, 2001; Yantis, 1992). At the same time, observers are able to maintain object continuity when such objects are occluded from sight. Seemingly, we are able to track the spatiotemporal changes of objects as they move across space, time and during occlusions. In fact, motion is so imperative to survival that neural processing has evolved to deal specifically with motion perception (Albright, 1984; Dittrich & Lea, 1993; Grossberg, Mingolla & Pack, 1999).

Given the ubiquity with which we deal with motion, it is no surprise to find that tracking dynamic objects has been investigated from a number of perspectives. What is surprising is the lack of research addressing which spatiotemporal information (location, motion, and direction) is encoded while tracking and recovering objects after occlusions. A current gap in our understanding includes a lack of knowledge of how spatiotemporal information is used to recover targets after occlusions. Is motion used to extrapolate moving objects to future locations or is it simply a matter of storing object location in memory?

The main goal of this thesis is to understand which spatiotemporal properties are encoded using a multiple object tracking paradigm (MOT) and how these properties are used to recover objects after occlusions. Specifically, this goal was addressed by investigating the isolated and combined impact of spatiotemporal properties on tracking and target recovery performance across long occlusions.

The research questions, as can be seen in Figure 1, focus on uncovering what information is encoded and recovered in multiple object tracking. The specific research questions of this dissertation are:

1. What spatiotemporal information is encoded in the tracking phase?
    a. Is motion important?
    b. Is direction important?
    c. Is location important?
2. How is spatiotemporal information stored or used during the occlusion?
    a. Are the targets tracked on-line or off-line?

b. Where is the information stored? Is it stored in working memory, long-term memory, or both?

3. What spatiotemporal information is helpful in the recovery of targets?

    a. Is motion important in target recovery?

    b. Is direction important in target recovery?

    c. Is location important in target recovery?

Tracking Phase	Occlusion Phase	Recovery Phase
What spatiotemporal information is encoded in the tracking phase?	How is spatiotemporal information Used? Is it stored off-line or tracked on-line? Where is spatiotemporal information stored? Is it VSTM, LTM, or both?	What spatiotemporal information is helpful in the recovery of targets?

Figure 1. Overview of the research questions integrated into MOT paradigm.

A review and discussion of the literature specific to these research objectives is presented in the following chapters. First, an overview of multiple object tracking theories is presented below, followed by a review and critique of these theories. Finally, the hypotheses and objectives are linked to current multiple object tracking theories.

Multiple Object Tracking

Research on cognitive processes, such as visual attention, memory, and even multitasking, has focused primarily on static stimuli. While static objects are stationary and not changing, dynamic objects undergo continuous change and progress over time (Kerstholt, 1994). The aim of this section is to better understand the processes involved in constructing, encoding, and maintaining the visual representation of dynamic environments. The most thorough area that deals with dynamic tasks was developed by Pylyshyn and Storm (1988) and is known in the literature as multiple-object tracking (MOT). MOT is a dynamic unpredictable tracking task that requires observers to attend to and keep track of dynamic targets that move amongst identical distracters across space and time. As described by Pylyshyn and Storm (1988) the MOT research paradigm uses a visual display, wherein a number of identical objects (dots) are presented to the participant. At this time the targets are not moving. A pre-determined number of these static dots are identified by flashing on and off indicating to the participant that these are targets. After a set period (typically a couple of seconds) the dots begin to move around in random and independent motion. After a few seconds of tracking, the targets cease moving and the participant is told to identify the targets amongst the distracters by clicking on the targets with the mouse. Participant accuracy in the number of correctly identifed targets is recorded as the dependent measure. The stepwise progression of MOT paradigms is presented in Figure 2.

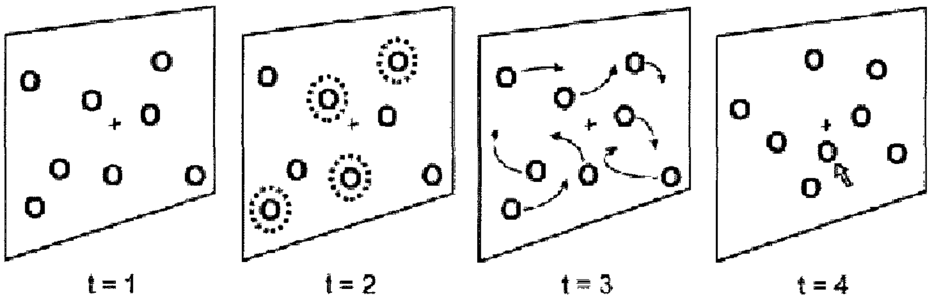

Figure 2. Multiple object tracking paradigm (MOT) as depicted in Pylyshyn and Storm (1988).

Consistently, MOT research has suggested that individuals are capable of re-finding up to four randomly moving targets (Pylyshyn & Storm, 1988; Intriligator & Cavanagh, 2001; Yantis, 1992). As such, researchers suggest an attentional limitation in dynamic tracking exists. One such theory proposed by Pylyshyn and Storm (1988), indicates that MOT is maxed out when the fixed number of attentional spaces or "indexes" are filled. Pylyshyn and Storm refer to these visual slots as FINSTs ("FINgers of INSTantiation"). They describe FINSTs as pointers (or fingers) which provide a location reference for targets. FINSTs function as a storage unity for location information and nothing else. Pylyshyn and Storm suggest that objects are tracked pre-attentively without the need for selective or focused attention. Others suggest that selective and focused attention is required to gain a more in-depth assessment of target information (colour, shape) (Tombu & Seiffert, 2008). Thus, if an individual wants to move beyond tracking he/she must allocate attention to the target object in order to extract more than location information.

In later revisions of this theory, Pylyshyn, Burkell, Fisher, Sears, Schmidt, and Trick (1994) moved away from strictly pre-attentive accounts of tracking by suggesting that tracking requires continuous and active attention. For instance, Pylyshyn et al. suggest that indexes need to "be periodically refreshed" (p.269) in order to keep location up-to-date and that directed attention is required to minimize the impact distracters have on target tracking. They also suggest that observers require attention in order to recover a target that has been lost. Pylyshyn (2004) indicates that the acuity by which participants are able to describe specific spatiotemporal properties, such as target direction and location, is greater than their ability to report the same properties of distracter objects. Nevertheless, participants are seemingly still unable to report when a target undergoes characteristic changes such as colour and/or shape (Bahrami, 2003). FINSTs are seemingly limited to providing information about *where* an object is, or was located, instead of providing information about *what* an object is.

Alternate theories have proposed that attention should be given consideration. Yantis (1992) suggested that participants track dynamic objects by combining them into a diagrammatic representation of a "virtual polygon" (p. 301). In the virtual polygon, the targets are represented by the nodes. Tracking occurs by collectively monitoring the change in size, shape, and position of the morphing polygon as it moves through space. Yantis found that participants who were cued to use the perceptual polygon, initially performed better on target tracking tasks in comparison to participants that were not cued to formulate a mental polygon. The advantage of the perceptual polygon was only present at the beginning of the task, while participants were still in the learning stage. Yantis found that participants who were told to use the perceptual polygon and those who were not reached similar levels of performance after the initial learning curve ended. After briefing the participants, Yantis found that the "non-polygon" group noted that they grouped targets based on geometrical shapes. Observers learnt to adopt the use of the perceptual polygon on their own. Yantis indicated that tracking accuracy depends on the complexity of the polygon's configuration, not necessarily on the number of objects. Although, there is a need to recognize that the configuration of the polygon is inherently linked the number of targets.

Another attention-based tracking theory is Kahneman, Treisman and Gibbs (1992) "object files". Unlike FINSTs, object files have storage space for more than just location, Object files can house information related to object identity, such as colour, shape, size and possibly spatiotemporal information (Barsalou, 1999; Hommel, Müsseler, Aschersleben & Prinz, 2001; Kahneman et al., 1992; Horowitz, Klieger, Fencsik, Yang, Alvarez & Wolfe, 2007). During MOT tasks observers would need to create one object file for each moving target they were tracking. According to Kahneman et al. when an object is visible the object file is kept "open", allowing for information about the target to be progressively updated. Updating information happens whenever the object moves or changes. Kahneman et al. suggests that the updating process requires attentional processing, where the original object file is attentively updated with new information. Updating is based on an assessment of differences between the first object file (object file 1) and the second object file (object file 2). If differences between the two exist then object file 1 is discarded and object file 2 becomes the new updated object file. Kahneman et al. propose that during this process attention is being switched to and from each object file in order to facilitate the updating process.

Early pre-attentive tracking theories, such as those described by Pylyshyn and Storm (1988), offer a valid explanation as to why location information is relied upon, whereas featural and spatiotemporal information, such as colour or speed, are largely ignored.

Yantis (1992) and Kahneman et al. (1992), on the other hand, present a more upfront function for attention and cognitive processing in tracking tasks. Thus allowing for a better indication of how both the features and spatial aspects of the objects are encoded, monitored, and updated.

Visual Attention and Working Memory

To better understand how we are able to track and update dynamic information we need to investigate the attentional and cognitive processes involved in this ability. According to Scholl (2008), visual attention demands that an individual consciously select particular aspects of an environment or stimulus, while restraining other stimuli which may distract ones attention away from the stimuli of interest. Scholl explains visual attention as having three components. The first deals with selectivity. Selectivity occurs when observers intentionally and consciously elect to focus on certain pieces of information. The second aspect focuses on resources. Scholl suggests that directing and suppressing attention requires the expenditure of attention based resources. In essence you can't look at everything in the environment with equal detail. Lastly, Scholl points to limitations in attention. Limited resources present attention with tradeoffs, wherein directing attention to one object is often at the expense of another object, thus restricting the observer's ability to process and attend to everything in his/her environment.

Evidence that Scholl's theory of visual attention is applicable to MOT was found by Iordanescu, Grabowecky, and Suzuki (2009). These authors manipulated tracking difficulty in an MOT paradigm by increasing the number of distracters creating a situation of "overcrowding". Results suggested that participants selectively directed their attention to targets as a compensatory method to the overcrowding. This finding, once again, indicates that attentional resources, such as those suggested by Scholl, are required in MOT as a means to drive the selectivity and resource allocation of attention during tracking tasks. Furthermore, Drew, McCollough, Horowitz, and Vogel (2009), presented electrophysiological support for attentional mechanisms in multiple object tracking. These researchers looked at differences between the N1 and P1 waveforms from the electroencephalograph, where an increase in N1 and P1 ERP waves are indicative of recognition or familiarity of the target. The results of their tracking experiment suggested that participants had larger more distinguished N1 and P1 ERP waves for targets than they did for distracters, suggesting that attention is directed and allocated in target tracking.

Allen, McGeorge, Pearson, and Milne (2004, 2006) found support for the use of both working memory (WM) and attention in MOT. In their experiments, participants were required to verbally indicate if numbers, which were presented visually, were less than or greater than five. When participants concurrently performed a tracking task along with the number task, tracking performance decreased. The decrement in performance suggests that split attention, along with memory for a goal task (categorization), interferes with tracking. Further, Oksama and Hyona (2004) found that individual differences in working memory (WM) capacity and attention switching abilities were predictive of performance accuracy in MOT. This claim is also supported by various other studies that have investigated the involvement of WM in the storage of dynamic information (i.e., Vogel, Woodman, & Luck, 2001; Alvarez & Cavanagh, 2004; Oksama & Hyona, 2004). Evidence for workload interference in MOT was found by Fougnie and Marois (2006) in an experiment that required WM resources along with a concurrent tracking task. They found that dual performance decreased WM capacity. Collectively these results can be taken together to suggest that memory and attentional resources are required in tracking.

The consensus from the aforementioned research, with the exception of indexing theory, is that attention is allocated to targets during MOT. Capacity limitations in MOT are in effect linked to attention and memory constraints (Oksama & Hyona, 2004). In line with Scholl's overview of visual attention, MOT requires attention to suppress the demands of distracters (Iordanescu et al., 2009; Scholl, 2008). In MOT this is attained by distinguishing locations from one another, not distinguishing features form one another. In effect, this makes MOT different from a visual search task (Wolfe, Horowitz, & Michod, 2007). It is expected that motion information, which is a spatiotemporal characteristic, is vital to the encoding and recovery of targets in MOT. Uncovering the use of motion information in encoding and recovery builds the foundation of the current thesis. A review of the spatiotemporal properties in MOT research will be discussed below.

Spatiotemporal Properties in MOT

Motion information distinguishes dynamic environments from static environments and is undeniably the most salient cue available in MOT. As discussed above, it is thought that spatiotemporal information such as direction, location, and speed is seemingly required to distinguish targets from one another during MOT tasks. Although, several properties of moving objects such as trajectory, speed, and direction are all readily available in MOT tasks, empirical evidence (i.e. Pylyshyn & Storm, 1988; Keane and Pylyshyn, 2006) suggests that motion information is not encoded during tracking. It is possible, that spatiotemporal information could be utilized differently in situations where targets were occluded, and therefore not being visually tracked. To assess this, Keane and Pylyshyn had participants perform a typical MOT task. The main difference between occluded tracking paradigms and traditional MOT paradigms is the occlusion phase. In occluded tracking, the screen was occluded for 150 msec, 300 msec, or 450 msec during which movement of the occluded targets was manipulated (as depicted in Figure 3). Targets were either displaced to new predictable locations just as though they had continued moving, or they remained frozen in their pre-occlusion location.

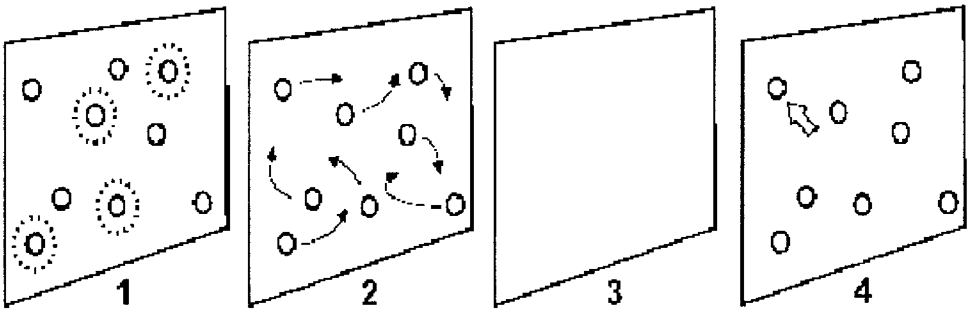

Figure 3. Multiple-object tracking paradigm with an occlusion as indicated by slide 3. Modified from Keane and Pylyshyn (2006).

They found that displaced targets were more difficult to recover than non displaced targets. Further, no significant differences for occlusion length were seen for the non-move condition, suggesting that short-term memory for a targets last known location lasts for at least 450 msec. These results were taken to mean that observers encode the location of objects and use the last known location to recover targets. Keane and Pylyshyn (2006) propose an "*off-line tracking*" mechanism to explain these results. Off-line tracking suggests that location information, not spatiotemporal information, is encoded. The recovery of off-line targets, therefore, requires individuals to predict the new location of the targets after an occlusion based on the last known location. The off-line hypothesis suggests that a mental snapshot of the objects locations are encoded in short term memory (STM) until it is time for retrieval.

Had the results shown decreased accuracy in the non-move condition, along with decreased performance when occlusion duration increased, the results would have best been explained by a continuous extrapolation of the invisible objects. This theory of continued invisible tracking is known as "*on-line tracking*". The on-line hypothesis predicts that invisible and visible tracking are identical. The on-line hypothesis borrows from the theory of representational momentum in that representational momentum suggests that momentum information is stored and used while tracking or extrapolating the location of targets. Specifically, representational momentum describes a process through which motion is consistently extrapolated during tracking (Freyd & Finke, 1984; Finke & Shyi, 1988). Based on representational momentum it is expected that spatiotemporal information can be encoded and used by observers to form a continuous, uninterrupted mental picture of the target object. This is not to say that online tracking and representational momentum are the same. Overall on-line and off-line theories of multiple-object tracking provide us with two views on how we integrate and keep track of dynamic information in our environment.

While Keane and Pylyshyn's (2006) results do not rule out the encoding and storage of motion information, they do suggest that on-line tracking is not used. Although the literature is still unclear, there is some empirical research, like those presented above, to suggest that spatiotemporal properties of motion are partially encoded during the tracking phase in MOT. Recent experiments by St. Clair, Huff and Seiffert (2010), measured target recovery during tracking while manipulating background movement. The background texture was set to remain static, or to move opposite or in the same direction as the target object, requiring the observer to focus on the target. Observers tracked 3 - 4 out of a set of 10 dots that moved in a predictable straight line path. Participants were instructed to track the targets and to use the mouse identify the targets once they stopped moving. St. Clair, Huff and Seiffert (2010) hypothesized that background motion would not affect recovery if motion information was not used to track targets. A significant difference between texture motion types (static, same, opposite) was found. When the background texture remained static or moved in the same direction as the target, observers were better at recovering targets in comparison to conditions with orthogonal or opposite background motion. St. Clair et al. suggest that these results point to the fact that motion information is used during MOT and is used to predict the future location of targets.

An inherent part of motion is direction. Although the aforementioned study by St. Clair, Huff and Seiffert (2010) pointed to the use of spatiotemporal information during active tracking, this study tells us little about the encoding of specific pieces of spatiotemporal information. Horowitz and Cohen (2010) looked specifically at the encoding of direction information by having observers track moving objects, and then using an adjustable arrow to indicate the direction the target was moving. The precision of their responses declined as the number of targets they were asked to track increased, but overall the results suggested that target direction was encoded and used during tracking.

In addition to direction, speed information is another critical spatiotemporal component. Research on the impact of speed in MOT is limited, but nonetheless it does seem to play a role in tracking performance. Research suggests that it is easier to track targets that differ from distracters by speed. Differing speeds allow targets to become more salient, and hence easier to track (Vul, Frank, Tenenbaum & Alvarez, 2009). Blake, Cepeda, and Hiris (1997) also reported that speed information can be encoded in WM for periods of greater than 10 seconds suggesting that speed is in fact encoded (Magnussen & Greenlee, 1992; Magnussen, Greenlee, Asplund, & Dyrnes, 1990; Regan, 1985).

On-line Hypotheses & Representational Momentum

Although research on MOT lacks conclusive evidence as to the encoding and use of spatiotemporal information, there is an interesting phenomenon that lends support to motion encoding (including direction and speed) in object tracking. This theory is widely known as representational momentum. Representational momentum is typically present in situations where moving objects (either through the presentation of stills or continuous motion) are suddenly occluded. Representational momentum was first documented by Freyd and Finke (1984) during an experiment where participants were asked to observe serial presentations of a rotating rectangle. After a brief encoding period of 250 milliseconds a probe rectangle was presented. The participants were asked to judge if the probe matched the location and spatial layout of last rectangle or not. When the probe rectangle was rotated a ahead of the true position of the pre-occlusion rectangle, Freyd and Finke (1984) found that participants concluded that the rectangle was in the same location. Further, they concluded that "forward displacements" of object motion was related to the perceived speed of the extinguished object. For instance, faster objects were located further ahead than slow objects. Trajectory was only used, however, when the trajectory of the target was predictable. Other experiments have found that participants, when asked to pinpoint the location of occluded objects, consistently locate the objects ahead of the locations where the objects actually disappeared. Based on the evidence above, it can arguably be concluded that observers encode momentum or trajectory information during tracking tasks (Freyd & Finke, 1984; Freyd & Johnson, 1987; Finke & Shyi, 1988).

Freyd and Johnson (1987) suggest that mentally represented objects have the same properties as physically moving objects in that stopping is gradual and not instantanous, resulting in forward displacements. Kerzel (2006) found that the addition of a distracter task during an occlusion mitigated the phenomenon of forward displacement, providing support for the necessity of attentional processing in representational momentum and occluded tracking. Moreover, Vinson and Reed (2002) found that knowledge of an objects "typical" motion (i.e., a rocket, a weight, or a drill rig) was enough to influence the force of the resulting displacement. These researchers found larger upward displacements for rocket ships than for weights. As such, it appears as though encoding typical spatiotemporal information about an object is part of tracking. All of the aforementioned experiments suggest that representational momentum requires attentional processing and encoding spatiotemporal information.

In order to investigate this phenomenon within the context of MOT, Iordanescu, Grabowecky, and Suzuki (2009) looked at whether or not attention was used to monitor and store target speed, location, and direction. Participants were asked to track three randomly moving targets amongst seven distracters. Each of the three targets was assigned a colour of red, green, or yellow. To minimize the participant's ability to track colours and not spatiotemporal characteristics the distracters also shared these colours, forcing the participants to attend to the targets. At the end of the tracking period, all of the circles disappeared from view. Once occluded, the participant was auditorily presented with the name of a colour. Participants were instructed to indicate where on the screen the target associated with that colour was located prior to the interruption. As is typical in representational momentum, participants consistently displaced the mouse-clicks ahead of the actual object. Furthermore, the extent of the displacement was positively correlated with the targets speed, meaning that faster targets had larger forward displacements than slower targets. Evidently Iordanescu and colleagues (2009) indicate that location, direction, and speed information are encoded during tracking and used to mentally extrapolate target positions, not to simply update target location ad-hoc.

Summary and Critique

Thus far, I have outlined the most influential experiments and resulting theories present in the MOT literature. Uncovering the use of spatiotemporal information in the encoding and the recovery phase of MOT builds the foundation of the current thesis. The aforementioned studies on spatiotemporal encoding and representational momentum, suggest that spatiotemporal information does play a role in MOT. The use of spatiotemporal information during the recovery stage is unclear. For instance, a number of researchers suggest that pre-occlusion location information drives target recovery in an off-line manner (Sears & Pylyshyn, 2000; Pylyshyn & Storm, 1988), whereas other theories point to the encoding, and therefore hypothesized use of spatiotemporal information in an on-line manner, in the recovery stage (Freyd & Finke, 1984; Freyd & Johnson, 1987; Finke & Shyi, 1988; Iordanescu, Grabowecky, & Suzuki, 2009).

Existing theories of MOT offer a variety of predictions about the attentional and cognitive processes involved in tracking dynamic objects. FINST theory suggests that tracking is automatic and not influenced by high-level cognitive processing. FINSTs suggest that location is the only piece of spatiotemporal information stored, leaving characteristics such as colour and shape ignored. On the other hand, Yantis' (1992) perceptual polygon, and Kahneman, Treisman, and Gibbs (1992) object files require attention during tracking tasks. These theories better describe how observers encode characteristics such as motion, colour, and identity information during tracking. The dynamic nature of MOT is unique in that it requires observers directed continuous attention to motion, whereas static displays can be maintained by momentarily directing attention to pieces of information that will remain in that location (Scholl, 2008).

Overall, the above presented research implies that spatiotemporal properties of dynamic objects do play a part in MOT. Uncovering the use of spatiotemporal information is especially important for target recovery in MOT tasks that implement occlusions. As such, there is a large gap in our understanding of spatiotemporal properties in the recovery of targets after occlusions. In addition to understanding what properties are encoded, I also wanted to understand how the information was stored and used during the occlusion. Investigating the use of spatiotemporal information from an on-line and off-line perspective is vital. It should be noted that off-line theories, as presented in the current literature, suggest that only location information is stored. It is, however, entirely possible that spatiotemporal information, beyond just location, is stored off-line and used to recover targets.

Critical Assessment of Post-Occlusion Information

A critical review of MOT research reveals that the majority of studies largely support the use of off-line tracking (Sears & Pylyshyn, 2000). It should be noted that these studies are artificially confounded with the removal of valuable spatiotemporal cues during the recovery phase. All of experiments which lend support to off-line tracking required participants to track multiple moving objects during the tracking phase, followed by brief occlusions, and finally recovery phase where participants were required to click on frozen targets. The fundamental issue with these experiments is the artificially frozen targets in the recovery stage, resulting in a lack of encoding specificity. In our everyday dynamic environment, it is very rare to have a moving object freeze in place after being occluded from view. It is more likely that we recover dynamic objects in our environment while they continue to move, such is the case while driving, playing hockey, or monitoring a radar screen.

By presenting participants with frozen targets in the recovery stage, researchers are stripping valuable spatiotemporal cues from the environment which may facilitate the recovery of moving objects. This method not only creates an ecologically artificial environment, but also a recovery phase that is different from the tracking phase. This brings to light Tulving and Thomson's (1973) encoding specificity theory, which suggests that retrieval of information is dependent on how the information was encoded. Congruency between encoding and recovery of information is necessary for retrieving features that were initially encoded. One implication of a lack of encoding specificity is that detriments in target recovery may be caused by a lack of retrieval cues, and not due to a lack of encoding, as has previously been suggested.

This suggests that if motion information is attentively encoded then same spatiotemporal information should be presented during the recovery stage. Making encoding and recovery information congruent allows me to better investigate the use of spatiotemporal information. Support for location encoding in previous experiments may be in part due to a lack of encoding specificity. It is important to better uncover the use of motion information during the encoding, representation, and recovery of targets. One goal of the current thesis was to manipulate the spatiotemporal information presented in the encoding and recovery phase. It is, therefore, postulated that removing spatiotemporal cues from the recovery stage hampers the use of spatiotemporal cues, except location information. Figure 4 provides an overview of the absence of encoding specificity in current MOT paradigms. Further, it is hoped that the results of this thesis are able to clarify the mechanism (off-line or on-line) by which these cues are used during the occlusion.

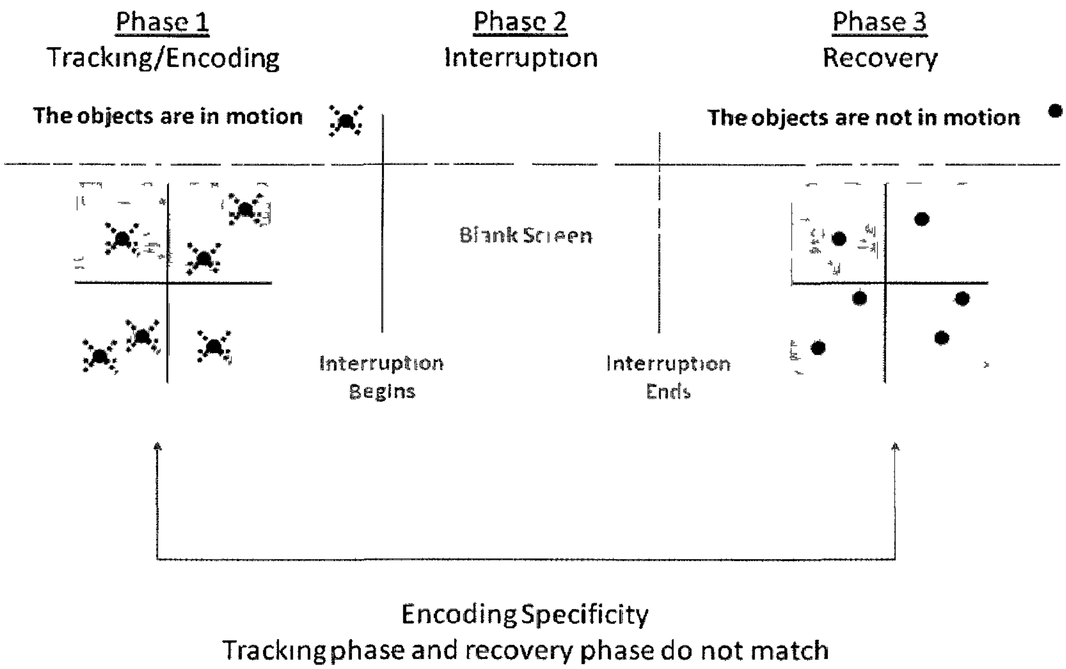

Figure 4. Schematic overview of the absence of encoding specificity in traditional multiple object tracking paradigms.

Critical Assessment of Occlusion Limitations in Current MOT Paradigms

A number of limitations to previous MOT paradigms will be discussed in this section. The first is the use of a very short occlusion period. It is important to consider that real-world judgements about dynamic objects often need to extend beyond a couple hundred milliseconds (Oinonen, Oksama, Rantanen, & Hyönä, 2009; Pylyshyn, & Storm, 1988; Scholl & Pylyshyn, 1999). Currently, there is a lack of understanding about the processes involved in recovering dynamic objects after occlusions that extend beyond the capacity limitations of working and short term memory. Thus, another goal of this thesis was to investigate the perseverance or longevity of encoded information. The intent was to underpin the functioning of on and off-line tracking in MOT during long occlusions. By extending the occlusion period from mere milliseconds to 30sec, the most likely mechanism at play becomes short-term memory (STM). Research suggests that the duration of "remembering" in STM is 18-20 sec. When rehearsal or some other mental processing is in play STM switches to working memory (WM) wherein, remembering may be extended to longer periods of time. Given that the occlusion period will last for longer than the expected longevity of STM we should be able to tap into the other potential memory stores, such as WM or LTM that may be used in MOT (Cowan, 2005). That is to say, those theories of on-line tracking which demand observers to perform mental visualizations would support the recovery of targets after a 30 sec occlusion, whereas off-line or location storage theories would suggest that recovery after a 30 sec timeframe would be nearly impossible. However, if information is actively tracked on-line during occlusions then spatiotemporal information may be maintained and the mechanism at play is most likely. As such, the extension of the occlusion period to 30 sec was proposed to help uncover how, and in what capacity, spatiotemporal information is stored and used during the 30 sec occlusion.

Overview of the Revised MOT Paradigm Designed for the Current Thesis

Given the limitations present in current MOT paradigms, the modified paradigm designed for this thesis allowed for a more realistic investigation of multiple object tracking. Additionally, the expansion of the current paradigm also allowed for the exploration of more theoretical aspects of MOT, such as long and short term memory storage. The modified paradigm had objects which were distinguishable from each other by an alphanumeric label representative of a call-sign, similar to those used to identify aircraft on air traffic control (ATC) radar screens. ATC is a real-life MOT task, wherein controllers need to monitor the dynamically changing aircraft so it seemed fitting to use call-signs as the identifiable feature instead of a pop out feature such as colour or shape. The use of call-signs, as distinguishing features, has also recently been implemented in MOT (Hope, Rantanen, & Oksama, 2010) and has proven to be a valuable featural characteristic. The new paradigm also presented objects moving on predictable and known trajectories and at predictable and known speeds to better replicate real-world parameters. A pilot experiment, presented in Appendix A, determined the suitability of these modifications prior to their implementation into the experimental paradigms presented below.

To date, MOT experiments have focused almost exclusively on accuracy, whereas interruption based experiments deal almost exclusively with reaction time. Given that an interruption shares some of the same parameters as an occlusion it was thought that theoretical implications from memory for goals theory could be easily implemented into MOT research. Altmann and Trafton's (2002) memory for goals theory, depicted in Figure 5, describes an interruption as having a primary task, an interruption lag, a secondary task, and a resumption lag. Although the current experiment does not require goal memory it was believed that the resumption lag was still relevant. The interruption literature defines the resumption lag as a measurement of how cognitively disruptive the interruption was to the primary task. Essentially, this is the time it takes for an individual to restart or "get-back-up-to-speed" on the main task after the interruption has ended. The measurement of resumption lag in this thesis provided a measurement of target recovery time. It was also used to supplement how information was used or stored during the interruption. For instance, a short resumption lag would suggest that the observer knew where the targets were. This may indicate that the participant had mentally tracked the targets during the occlusion allowing for them to quickly find displaced targets. A long resumption lag may suggest that the participant did not encode vital spatiotemporal information and instead needs to perform an ad hoc recovery of targets using location information. Specific hypotheses related to the resumption lag are provided for each experiment.

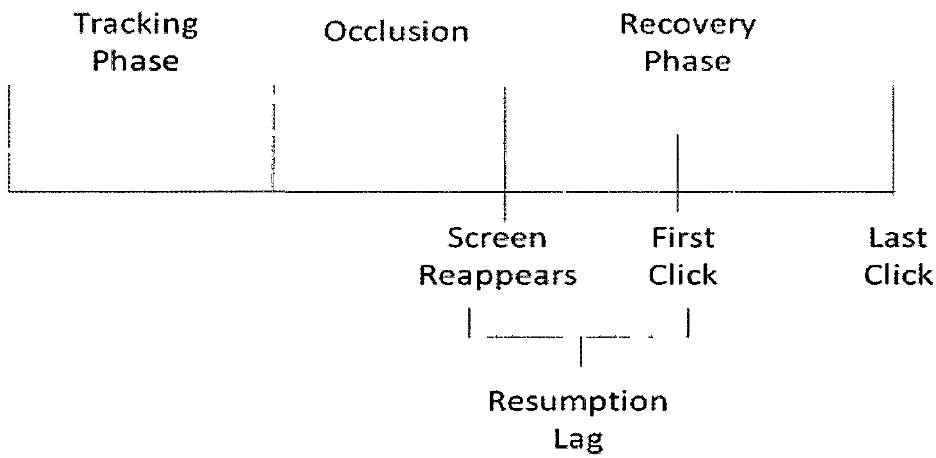

Figure 5. Diagrammatic representation of a resumption lag. Modified from Altmann & Trafton (2002).

Overall, the new paradigm had targets which were distinguishable from each other with alphanumeric call-signs, moved on predictable trajectories, and at predictable speeds. The occlusion length was 30 seconds. These modifications were deemed necessary to make MOT paradigms more ecologically valid and applicable to more real-world scenarios. The following is a detailed outline of the key features of the new MOT paradigm, with each compared to existing paradigms and the reasons for the modifications:

1. Predictable speeds and straight-line trajectories

a. Typical MOT tasks depict dots with random motion, speed, and trajectory which may limit an individual's ability to predict the displaced location of the target. It is possible that participants overreliance on location is a result of the unreliability of spatiotemporal information such as speed and direction. Given that encoding spatiotemporal information was important for this thesis, it was deemed necessary to have reliable spatiotemporal information present so that it could be predictably encoded and used in the recovery of targets.
b. Further, the enhancement of predictability also adds to the ecological validity of the paradigm, both in the way we track real-world objects and in the way targets are displayed in radar based tasks.

2. No collisions between objects
   a. The removal of collisions from MOT paradigms adds to maximizing the predictability of target trajectory as explained above. Previous MOT paradigms allowed collisions between targets that came into contact with each other resulting in changes in trajectory and speed.
   b. Enhancement of ecological validity wherein real-world object are independent of one another's movements. Typically real-world objects do not collide with one another, ricochet and take on another path of motion.
3. Number of targets increased to 6 and number of distracters increased to 8
   a. Number of targets was increased in order to compensate for the reduced difficultly of the task given the predictable speeds and trajectories. Research by Scholl, Pylyshyn and Feldman (2001) found that motion complexity was correlated with decreased performance in tracking targets. Given that target

movement in the new paradigm is less complex than original MOT paradigms, increasing the number of targets was required in order to minimize the chances of a ceiling effect.

b. With respect to ecological validity this change follows multiple-object tracking research done with air traffic controllers by Allen, McGeorge, Pearson & Milne (2004), which also required participants to track 6 targets. Additionally, more recent research by Hope, Rantanen & Oksama (2010) using MOT paradigms as an ATC display found that the use of 14 objects on the screen was manageable without resulting in a ceiling or floor effect.

4. Alphanumeric labels placed on the upper right side of each object
   a. Added ecological validity in comparison to previous MOT paradigms which used cued tracking instead of requiring participants to attentively track targets.
   b. The specifications of the alphanumeric data tags were based on data tags used by Hope, Rantanen & Oksama (2010).
   c. The addition of data tags makes the MOT task endogenous instead of exogenous tracking which is typical in MOT tasks. Endogenous tracking requires the use of serial and continuous selective attention. According to Fisher (2007) endogenous attention is typically required in order to perform tasks which require categorization and/or problem-solving. Basically, these are tasks that require focused attention and decision making. Exogenous tracking refers to an automatic or pre-attentive form of tracking. As such it can be argued that target tracking in our everyday environment is mostly endogenous. Certainly it can be argued that domains such as ATC require

endogenous tracking, whereby attention is directed to particular targets based on particular rules or characteristics. Further, it appears as though participants are still able to track and accurately find targets when they need to be tracked endogenously (Pylyshyn & Annan, 2006).

5. Longer occlusions

    a. Little and Bloomfield (1984) compared the difference between 15-30 second interruptions with those of 40-90 second and 90-120 second interruptions in a moving target radar task to determine radar operator's abilities to maintain focused tracking in one particular area of a radar screen. Based on the results it appeared as though performance was optimal, but not at the ceiling, when the interruption was around 30 seconds. Performance dropped significantly at the 60 and 120 second marks. Since this is one of the only experiments that implement long-term occlusions during a radar tracking task the results were used as a guideline in the determination of occlusion length for the current paradigm. As such, it was decided that for the current experiment that the optimal occlusion length would be 30 seconds to allow for good performance without floor or ceiling effects.

    b. Longer occlusions were also used as a way to tap into the memory storage of spatiotemporal information. Of particular importance to this thesis is the storage of spatiotemporal information. In line with this, Elliott, Jones, & Gray (1990) had participants identify a target after a 30 sec visual occlusion as a way to study memory for spatial location.

A pilot experiment was completed to determine if the changes were adequate for experimentation. The results of the pilot experiment were similar to those reported in previous MOT studies (i.e. Keane & Pylyshyn, 2003; Alvarez, Wolfe, Horowitz, and Arsenio, 2001). There were no ceiling or floor effects. The results replicated those found in earlier studies, so it was concluded that the current paradigm was applicable to use in the proposed study. Therefore, current MOT theories were applicable and are used in the explanation of the results. The intent in modifying the paradigm was to view MOT from a more ecological perspective, and test the propensity with which current theories can be extended to include longer more realistic occlusions. The results of the pilot experiment also provided support for the use of resumption lag as a dependent variable. Significant differences in resumption lag were found among the various displacement conditions, lending support to off-line theories of MOT (Hunter & Parush, 2010).

General Research Questions and Hypotheses

This thesis aims to examine the role of spatiotemporal information, specifically motion, in MOT. Although previous research has investigated the use of motion and direction cues during tracking no prior research has manipulated spatiotemporal information in the encoding and recovery phase of MOT, as a way to tease out the isolated and combined impact of these parameters on target encoding and recovery. These findings extend beyond a general understanding of encoding and recovery, to also include an understanding of how spatiotemporal information is used during occlusions. Overall, this thesis investigated what spatiotemporal information was encoded during the tracking phase, how encoded information was utilized during occlusions, and how the presentation of recovery phase information helped in the recovery of targets. A complete overview of the proposed questions is presented in Figure 6.

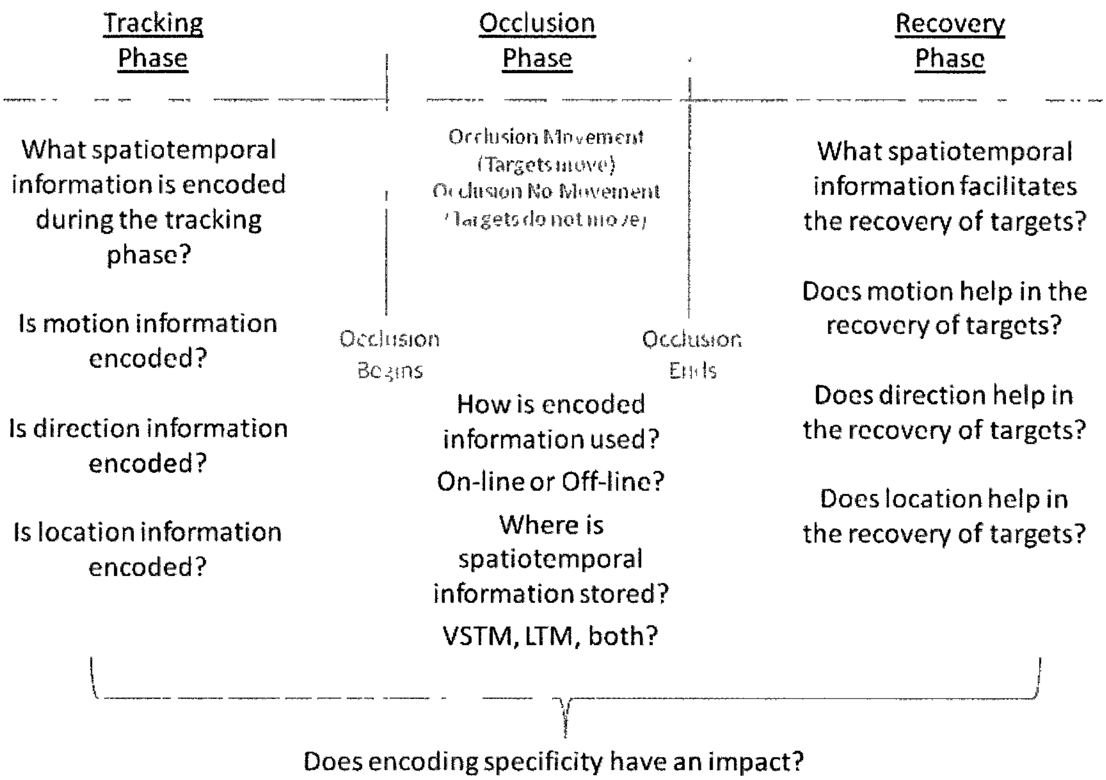

Figure 6. Detailed overview of the research questions in the current thesis.

Based on the review and critique of the aforementioned literature, it was hypothesized that motion information is used in addition to location. It was hypothesized that location and motion together would be encoded during the tracking phase, and would subsequently aid in the recovery of targets when presented in the recovery phase (Experiment 1). In order to tease apart the isolated impact of direction information, Experiment 2 dealt specifically with the use of direction cues in the recovery phase of MOT. It was hypothesized that directional cues would be encoded and used in the recovery of targets, but that performance would be lower than that seen in the Experiment 1. The difference in performance between these experiments was formulated based on the hypotheses that motion provides a more comprehensive view of MOT, and therefore is more valuable than only directional information. In order to control for the lack of encoding specificity issue presented above, it was necessary to completely cross all of the spatiotemporal information (direction, motion, direction +motion) in Experiment 3. Overall, it was expected that motion would be necessary to attain accurate performance in both the encoding and recovery stages of MOT. Figure 7 provides an overview of the proposed objectives of the three experiments in addressing the overall goal of the thesis.

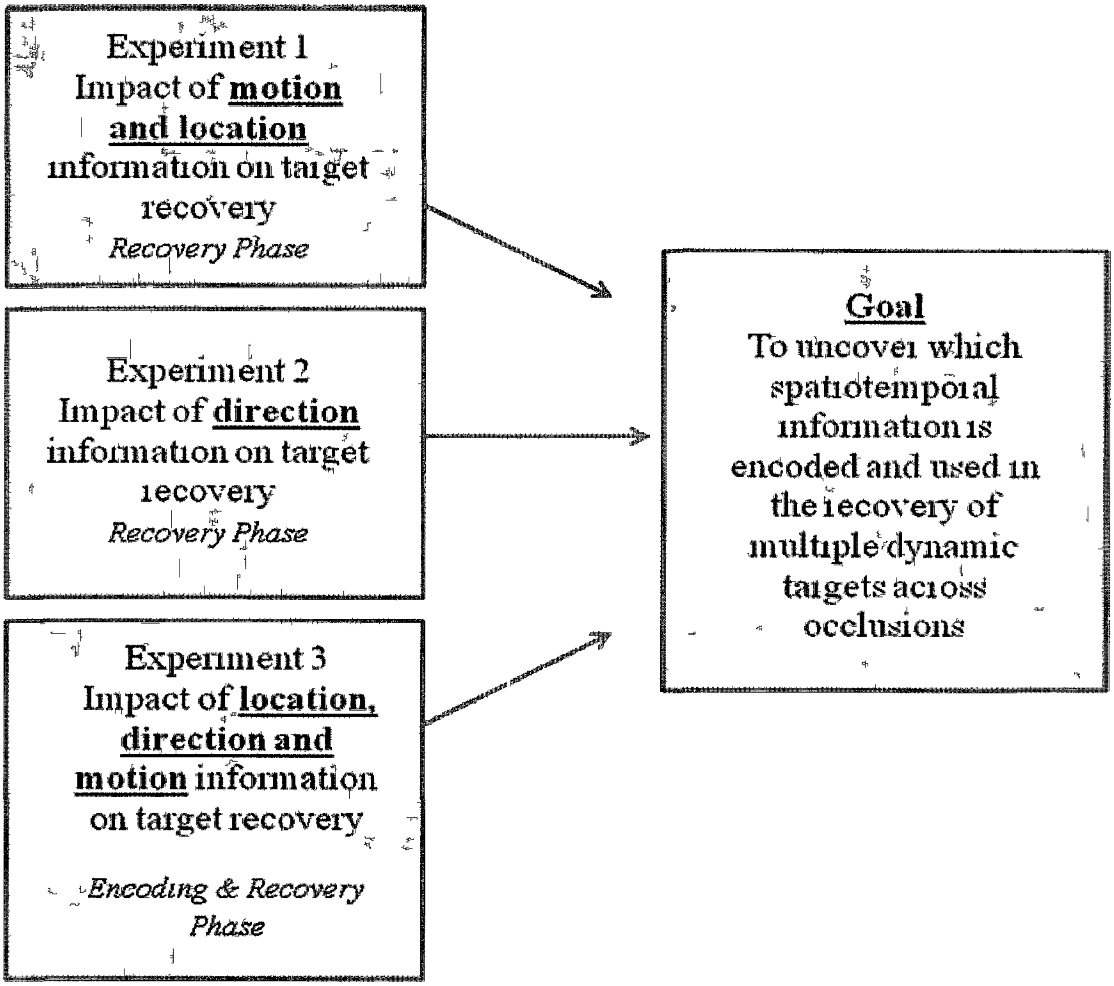

Figure 7 Objectives of the three experiments and the relationship to the overall goal of the thesis.

General Method

Materials

This experiment employed a modified version of the traditional MOT paradigm. The MOT paradigm used in this experiment was programmed in C++ and presented on a desktop computer. The stimuli consisted of 14 grey dots presented on a black background. Each dot had a five character alphanumeric label located to its upper right (ex. CA115). The tracking screen was split into four equal quadrants which were defined by grey lines. As soon as the scenario was launched the targets began to move without delay. Each dot on the screen moved on a straight-line path on either the x or y-axis. The dots moved from left-to- right, right-to-left, top-to-bottom, or bottom-to-top. Object trajectories were created prior to the experiment by using a text file that was fed into an exe file. Object movement was continuous, smooth and occurred in real-time. The movement of the targets and distracters were completely randomized across all 12 trials. Speed of the objects ranged randomly from 4.8 pixels/sec to 16.8 pixels/sec. Speed was randomized across all objects but remained constant through-out the scenario. When a dot intercepted the edge of the screen the x and y vectors were reversed making the dots appear to "bounce" off the side of the screen, meaning that they reverse their current path of motion. The speed of the dots during and after the "bounce" remained consistent.

Procedure

In accordance with the Carleton University ethics guidelines, an informed consent form was given to each participant prior to beginning the experiment. The informed consent form was explained to the participants, read by the participants, and then signed. A copy of the informed consent form can be found in Appendix B. Following the completion of the informed consent participants were asked to complete a demographics questionnaire. A copy of the demographics questionnaire can be found in Appendix C. Prior to commencing the actual experiment participants familiarized themselves with the task during a five minute training session. During the training session, participants were instructed to track all six dots labelled with a "CA". Participants then moved on to the completion of the actual experimental trials. The details of the experimental trials for each of the three experiments will be discussed in the appropriate sections below. At the end of the experiment the goals and hypotheses of the experiment were explained to the participant and they were given a copy of the debriefing form. A copy of the debriefing form can be seen in Appendix E.

Measures

Performance accuracy.

Accuracy was defined as selecting a correct target. In this experiment, a correct response was obtained by clicking on a "CA-target" in the post-screen. This was recorded as a dichotomous variable (correct or incorrect).

Resumption lag.

Resumption lag was recorded in seconds. It was defined as the time it takes the observer to click on the first correct target after the occlusion ended.

Experiment 1

One recent topic of research in multiple object tracking has been to specify which spatiotemporal information (location, direction, speed, motion) are used in tracking and recovery (Iordanescu, Grabowecky & Suzuki, 2009; Oinonen, Oksama, Rantanen, & Hyönä, 2009; Suganuma & Yokosawa, 2004). Motion information, which includes speed and direction, is thought to be used in the prediction of the future position of at least two objects over time (Iordanescu, Grabowecky & Suzuki, 2009). Although previous studies have used multiple object tracking tasks to investigate the use of motion parameters, there has been no definitive evidence for the use of motion information during the recovery of targets after occlusions. Given that motion information is thought to help in the tracking of objects (Iordanescu, Grabowecky & Suzuki, 2009; Verghese & McKee, 2002), it is expected that motion cues will facilitate object recovery after occlusions. Investigating what information facilitates recovery of targets will help reveal what spatiotemporal information is encoded. If motion serves as a cue in the recovery phase, it could imply that motion information is encoded during tracking and stored in memory during occlusions. It is also necessary to consider what happens to encoded motion information when objects continue to move or remain stationary during the occlusion. It is possible that motion information may not be valuable in target recovery in situations where dots remain stationary during occlusions, whereas motion may be much more valuable to recovery in situations where dots continued moving. That is, motion information may be the crucial piece of information required to recover displaced targets.

Prior multiple object tracking experiments have halted the movement of targets during the target recovery phase. The artificial freezing of targets during the recovery stage, limits the use of motion information during target recovery. Consequently, this limits the ability to study the impact of motion information in MOT. The first experiment aimed to create an opportunity for encoding specificity by providing observers with motion information in both the tracking and recovery phase. Moreover, this experiment examined the use of motion information after a long occlusion, wherein targets continued moving or did not continue moving during the occlusion. The following hypotheses were investigated in Experiment 1:

1. Is spatiotemporal information, specifically motion, encoded and used in the recovery of targets in multiple-object tracking paradigms? To investigate this, the post-occlusion stage was used to facilitate opportunities for encoding specificity. If motion information was encoded and used, it was hypothesized that the presence of motion information in the recovery phase would lead to better

performance when compared to conditions that did not contain motion information.

2. How does recovery phase motion differ with respect to the movement of the targets during the occlusion (occlusion movement; occlusion no movement)? Uncovering how observers use spatiotemporal information (on-line or off-line) during the occlusion is difficult to verify. Thus, the following hypothesis is speculative. It was hypothesized that if motion information was used in an on-line manner then performance and resumption lag for the motion condition, when objects are displaced, would be faster and more accurate. This is because the post-occlusion recovery screen would match the cognitively extrapolated positions of the objects.

Method

Participants

Eighteen undergraduate students (14 females; 4 males) from Carleton University participated in the study. All participants were right handed and had normal or corrected-to-normal vision. Their ages ranged from 18 to 20 years (M = 18.7 yrs, SD = 3.86 yrs). Participants that participated in previous MOT pilot experiments were ineligible to participate in this experiment.

Research Design

This experiment implemented a mixed design. A mixed design was chosen over a fully within design to avoid over taxing the participants and because of time restrictions. There was a between-subjects variable that manipulated movement of the objects during the occlusion (occlusion movement, occlusion no movement) and a within-subjects variable that manipulated movement during the recovery phase (recovery phase movement, recovery phase no movement). Figure 8 provides a schematic representation of the above discussed experimental manipulations.

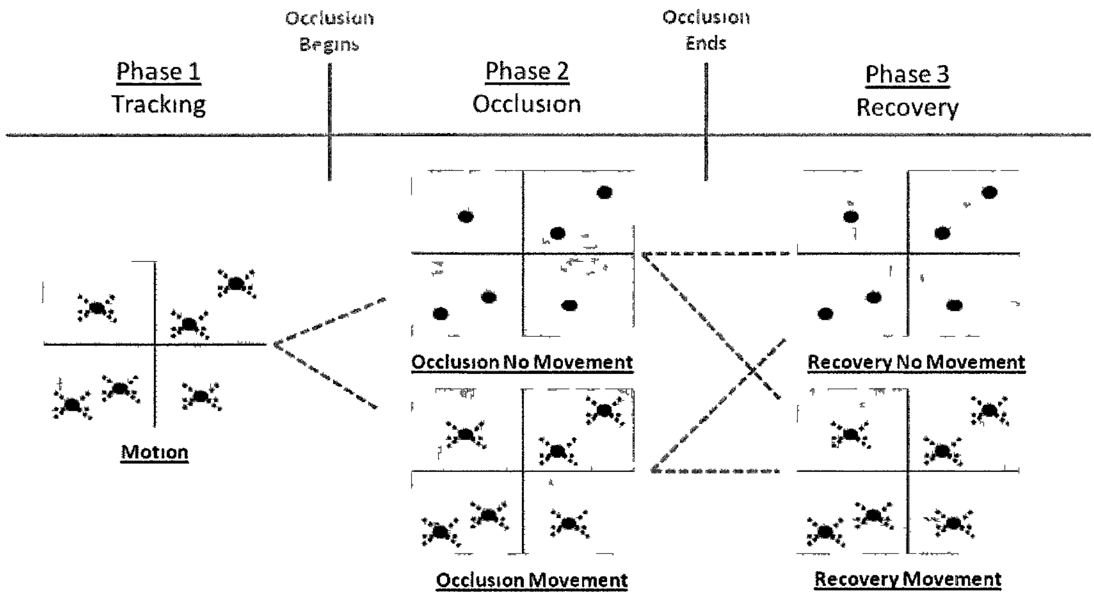

Figure 8 Overview of experimental design for Experiment 1. Targets in the occlusion phase move during the occlusion or remain static. Objects in the recovery phase are presented as static objects or they continue moving. The occlusion and recovery phases are completely crossed. The "CA" labels are not included in the tracking phase of this diagram, but they were present during the actual experiment.

Procedure

Following the training session participants began the experimental task. Participants were randomly assigned to either the *occlusion movement* or *occlusion no movement* condition. Next participants proceeded to complete two fully within counterbalanced experimental conditions (*recovery phase no movement* and *recovery phase movement*). Participants were instructed to track the six "CA" targets for a randomized duration (25-

35 seconds) amongst eight distracters. Randomization of tracking time was used to decrease the predictability of occlusion onset. After the tracking phase ended, the tracking screen was occluded by a black screen. Participants were instructed to stare straight ahead during the occlusion period. The occlusion period lasted for 30 seconds after which the tracking screen with unlabelled dots reappeared. In the *occlusion no movement* condition, the dots did not change their location during the occlusion and re-appeared in their pre-occlusion locations. In contrast, during the *occlusion movement,* condition dots kept moving at the same speed and direction and reappeared in a new position after the occlusion ended. Immediately after the tracking phase, the screen froze and all alphanumeric labels disappeared. Participants were then instructed to use the mouse to click on the six "CA" targets. Once a dot was clicked it turned red and could not be un-clicked. After the participants clicked on six targets they were instructed to hit enter to move on to the next trial.

Results

Data cleaning and assumptions

All dependent variables were checked for outliers, missing data, normality, and homogeneity of variance. The data can be assumed to comply unless otherwise indicated. The assumption of homogeneity of variance was assessed using Levene's test.

Performance accuracy.

An initial repeated measures analysis on time block was performed to ensure that there were no practice or fatigue effects present in the experiment. No significant differences in performance accuracy between the beginning (trials 1-4), middle (trials 5-8), and end (trials 9-12) were found, $F(2, 16) = 0.32, p = 0.73$. Further, no significant interactions were found. For all following analyses performance was collapsed across all trials.

Accuracy was analyzed by a 2 Occlusion Motion (occlusion phase movement versus occlusion phase no movement) x 2 Recovery Motion (recovery phase motion versus recovery phase no motion) mixed model ANOVA. The results indicated a significant Occlusion Motion x Recovery Motion interaction, $F(1, 16) = 6.23, p < 0.05, \eta^2_p = 0.28$. As depicted in Figure 9, the interaction suggests that recovery phase motion facilitates target recovery when objects move during the occlusion, but motion does not make a difference in target recovery when targets reappear in their prior locations (no occlusion motion). It is particularly interesting to note that target recovery performance is at the same level as the no occlusion movement level when recovery phase movement is present. In general, this result suggests that motion is encoded and used in some form during the occlusion. The use of motion information during the occlusion is still unclear but implications will be discussed. A significant main effect for Recovery Motion, $F(1, 16) = 5.43, p < 0.05, \eta^2_p = 0.25$, and a significant main effect for Occlusion Motion, $F(1, 16) = 5.70, p < 0.05, \eta^2_p = 0.26$, were also found.

To further investigate the interaction, a paired sample t-test was conducted to determine if there were significant differences between recovery phase motion and recovery phase no motion when occlusion motion was present. The paired sample t-test revealed significant differences between recovery phase no motion and recovery phase motion when occlusion motion was present, $t(8) = -2.85, p < 0.05$. As depicted in Figure 9, the interaction suggests that motion information facilitates target recovery when objects move during the occlusion, yet motion does not facilitate recovery when the targets do not move during the occlusion.

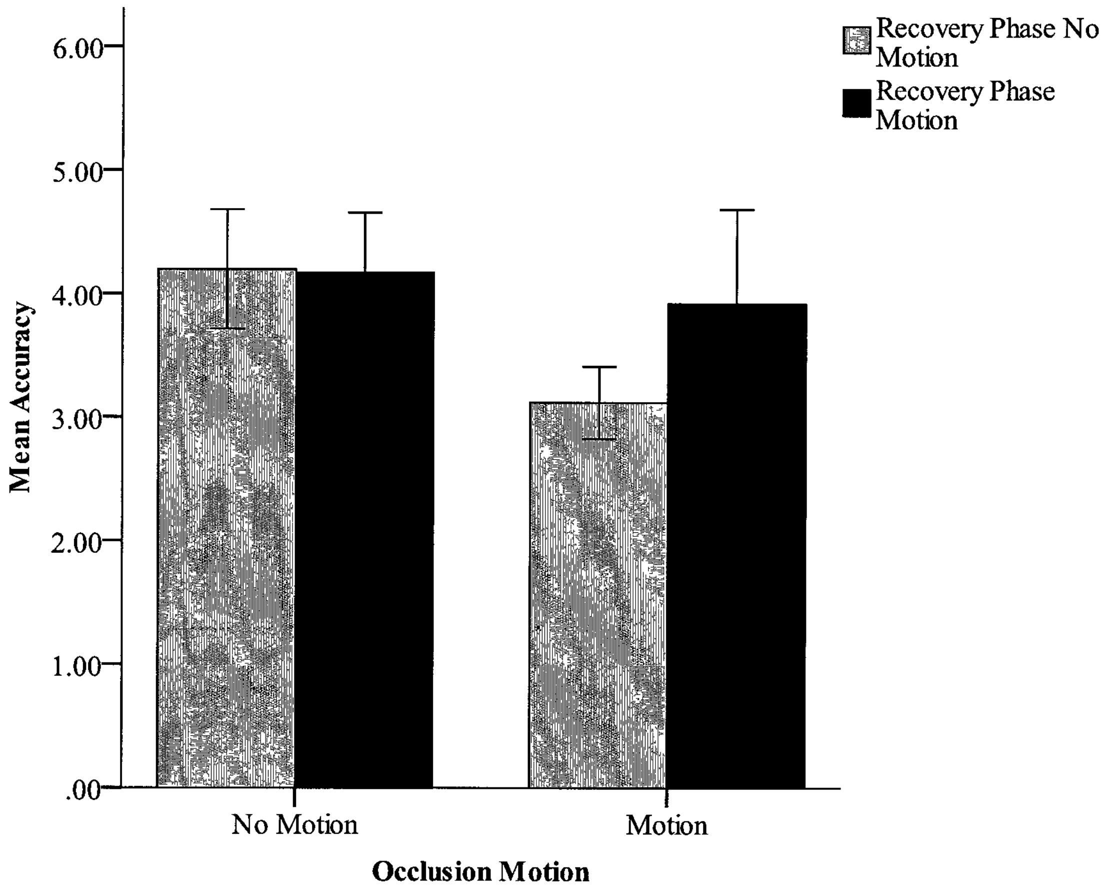

Figure 9. Bar graph depicting a significant Occlusion Motion x Recovery Motion Interaction with 95% Confidence Intervals (CI's). The interaction suggests that motion information facilitates target recovery relative to the no motion condition when objects are displaced, but motion does not facilitate recovery in the occlusion not displaced condition relative to the no motion condition.

Resumption lag.

Resumption lag was measured as the time to first correct click after the occlusion ended. Only those trials where the first click accurately identified one of the CA targets were included in the analyses. Initial repeated measures ANOVA on time block was assessed to ensure that there were no practice or fatigue effects. No significant differences in resumption lag between the beginning (trials 1-4), middle (trials 5-8), and end (trials 9-12) were found, $F\,(2, 16) = 0.43, p = 0.62$. In addition, no interactions were found and for all following analyses resumption lag was collapsed across all trials.

A 2 Occlusion Motion (occlusion phase motion versus occlusion phase no motion) x 2 Recovery Motion (recovery phase motion versus recovery phase no motion) mixed model ANOVA was run on resumption lag. There was no significant main effect for Recovery Motion $F\,(1, 16) = 1.67, p = 0.22$, or Occlusion Motion x Recovery Motion, $F\,(1, 16) = 0.36$ $p = 0.56$ was found. A marginally significant main effect for Occlusion Motion was found, $F\,(1, 16) = 4.14, p = 0.06, \eta^2_p = 0.21$. The marginally significant main effect indicates that the time to locate the first target in the occlusion motion condition was slightly longer ($M = 4.73$, $SD = 1.94$) than the occlusion no motion condition ($M = 3.18$, $SD = 2.08$).

Discussion

Unlike original MOT occlusion studies, which do not address the use of motion information in the target recovery phase, the current experiment suggests that the presentation of motion in the recovery phase facilitates target recovery, but only when the targets have moved during the occlusion (occlusion phase motion). The difference between this experiment and the myriad of other studies is the unique employment of motion during target recovery. Further, the significant interaction between occlusion motion and recovery motion suggests that recovery phase motion improves target recovery accuracy in the occlusion motion condition to a level that is comparable to the occlusion no motion condition. A comparison of accuracy between recovery motion and recovery no motion when occlusion motion was present, shows a significant drop in accuracy when there is no recovery phase motion. Taken together, these results suggest that motion information is a valuable cue in reducing uncertainty in situations where targets have moved during the occlusion period. Recovery phase motion, in comparison to no-motion, was not helpful in situations where the targets did not move during the occlusion. As evidenced by other experiments, observers have a high sensitivity to detect targets which reappear in their prior locations. It appears as though location is the most reliable cue to use when targets did not move during the occlusion.

The accuracy results presented above seem to support location encoding (e.g., Keane & Pylyshyn, 2006; Oinonen, Oksama, Rantanen, & Hyönä, 2009; Scholl, 2008). The resumption lag results provide additional support in showing that targets which reappear in their prior locations have quicker resumption lags. This suggests that recovery phase information and encoded information are similar, allowing for quicker recovery. In cases where recovery phase motion is not present, as is the case in almost all MOT experiments, location information is probably the most readily available parameter by which to recover displaced targets (Keane & Pylyshyn, 2006). It seems plausible that location information is heavily relied upon because it is the only available information when targets are static. This would explain why MOT experiments overwhelmingly support theories of location encoding.

On-line tracking predicts that targets mentally continue moving during occlusions. Therefore, targets that move during occlusions should yield better performance than conditions that freeze during occlusions. Additionally, targets that continue moving after occlusions should also match the mentally tracked on-line targets. As such, it was hypothesized that the best performance would occur in conditions where targets continued moving during occlusions and continued moving in the recovery phase. This condition would result in a match between the recovery phase targets and the observers mentally extrapolated position of the targets during the occlusion. Although recovery phase motion did help in the recovery of targets that had been displaced during the occlusion, the resumption lag results did not support the above presented hypothesis. The resumption lag results instead suggest that targets which moved during the occlusion took longer to recover than non-moving targets, even when recovery motion was present. Alternatively, it is possible that motion information was encoded but not used in an on-line manner. It is possible that a combination of location information and motion information are stored off-line and used to perform backward extrapolations. Backward extrapolation refers to a hypothesized process by which an observer extrapolates to the previous location the target (prior to the occlusion) using what they see (motion, direction, location) in the recovery phase. In backward extrapolation, observers extrapolate back to the last observed location of a target before occlusion. The off-line storage of motion information would explain the slower resumption lag. It may also help explain why motion did not improve the recovery of targets that didn't move during the occlusion; albeit performance was also not made worse by the presence of motion.

The significant occlusion phase x recovery phase accuracy results suggest that the availability of motion cues after the occlusion help "fill-in-the-blanks" during recovery making the targets more easily identified. This facilitates target selection in situations where targets moved during the occlusion. The results of this experiment suggest that objects are thought to maintain their momentum through time and space by utilizing the spatiotemporal information which was encoded. Horowitz, Birnkrant, Fencsik, Tran, and Wolfe (2006) suggest that the disappearance of objects triggers the encoding of location into memory. Long-term storage of motion information (both orientation and speed) is supported by psychophysical studies that employ delayed discrimination paradigms (Bennett & Cortese, 1996; Magnussen & Dyrnes, 1994). In delayed discrimination experiments, accurate discrimination of motion information has been found to last upwards of 50 hours (Magnussen & Dyrnes, 1994), which is well beyond the 30 sec time frame imposed in the current experiment. Although understanding the long-term storage of motion information is important, it does not in itself explain why recovery phase motion facilities target recovery.

As alluded to above, it is possible that the availability of motion activates the encoded locations making the targets easier to recover. Support for this comes from Matthews, Benjamin and Osborne (2007) who found that memory for motion was superior to memory for static tasks when participants performed a scene recognition task. They also found that congruency in presentation during the pre and post-test stage, improved recognition of moving scenes after both 24 hour and 1 week intervals. In another study, Buratto, Matthews, and Lamberts (2009) suggest that there is a "dynamic superiority effect" wherein spatiotemporal information helps link storage and recovery of spatiotemporal properties. Mathews et al. goes on to suggest that a "motion schemata" needs to be activated in the post-screen by motion in order for observers to recover dynamic information stored during the pre-screen. In the current study, it is possible that the presence of post-occlusion motion activated a stored motion schema, allowing for a more accurate recovery of the displaced targets. An extension of this logic, suggests that the non-moving displaced targets were particularly difficult to find since the stored schemata was not activated by motion during the recovery stage, making recovery of non-moving targets difficult. If on-line tracking does not take place one of two things could be happening- there is active rehearsal of location and motion information, or the spatiotemporal information is stored in long-term memory.

In conclusion, the significant occlusion phase by recovery phase interaction found in Experiment 1 implies that motion information is encoded in MOT. Evidence for the use of motion information during the occlusion is not conclusive, although it appears to be stored off-line. Motion information may be used by some form of backward extrapolation, or it may be that recovery phase motion information activates a motion schema allowing observers to relocate the current location of the displaced objects (Matthews et al., 2007). It is more likely that motion information is encoded in MOT during the tracking phase and the encoded spatiotemporal information, if available in the recovery phase, is used to recover targets after occlusions. From this experiment, it is unclear if motion as a whole is encoded, or if separate spatiotemporal information parameters such as direction or speed are encoded and used. As such, Experiment 2 investigated if direction alone was enough to facilitate target recovery in MOT.

Experiment 2

The results of Experiment 1 suggest that post-occlusion motion facilitated the recovery of targets when the targets were displaced during the occlusion. The significant occlusion phase by recovery phase accuracy results in Experiment 1, suggest that motion is important in recovering targets that moved during the occlusion. Based on the results of Experiment 1, the use of spatiotemporal information is hypothesized to occur off-line. It is important to note that motion information is composed of both speed and direction information. As such, it is difficult to discern whether motion as a whole is responsible for the facilitation of target recovery or if direction information is an equally sufficient cue to facilitate recovery.

It seems intuitive that one would need to encode the direction of a target in order to recover it, yet Oinonen, Oksama, Rantanen and Hyona (2009) found that directional cues were only helpful when they pointed directly at the expected location, and not the previous location, of the displaced target. These researchers suggest that direction is not used in multiple object tracking. In contrast, Song and Jiang (2006) found that featural characteristics such as colour were not encoded, but observers were able to encode spatiotemporal directional information. Further, Tripathy and Barrett (2004) found that although direction encoding was possible it was limited in capacity to one target. In order to fully understand what spatiotemporal properties were encoded, it was essential to isolate direction and motion properties from one another and investigate their isolated impact on target recovery. As such, Experiment 2 aimed to investigate if direction information in the absence of motion can facilitate target recovery.

The following hypotheses were investigated in Experiment 2:

1. Is direction information, in the form of an arrow, when presented in the recovery phase enough to aid the recovery of targets in multiple-object tracking?
    a. Experiment 1 resumption lag results implied that targets were not tracked in an on-line manner; therefore it is possible that target recovery may not require all of the spatiotemporal information provided by motion. It is possible that

direction information may provide enough information for the observer to recover targets. Following this logic, it is hypothesized that direction information by itself, presented as arrows, will facilitate target recovery accuracy better than a complete lack of spatiotemporal information.

b. It is possible that direction, in the absence of motion, may increase the cognitive processing required to recover targets. When direction information is present (as an arrow with no motion) there is a need to process the direction implied by each arrow. As such, it is hypothesized that resumption lag for target identification in the arrow condition will be longer, but more accurate than the no arrow condition.

Method

Participants

Twenty undergraduate students (10 females; 10 males) from Carleton University participated in the study. All participants were right handed and had normal or corrected-to-normal vision. Their ages ranged from 17 to 29 years (M = 20.0 yrs, SD = 3.10 yrs). One participant did not indicate her age on the demographic questionnaire. Individuals that participated in experiment 1 were ineligible to participate in experiment 2.

Materials

This experiment employed the same stimuli as was described in the general methods section above. The main difference for this experiment was the presentation of arrowheads during the recovery screen. The arrows were located at the centre of the dot. The arrows were 3 pixels in thickness, and 15 pixels in length. See Figure 10. for a screenshot of the arrows presented in the recovery phase.

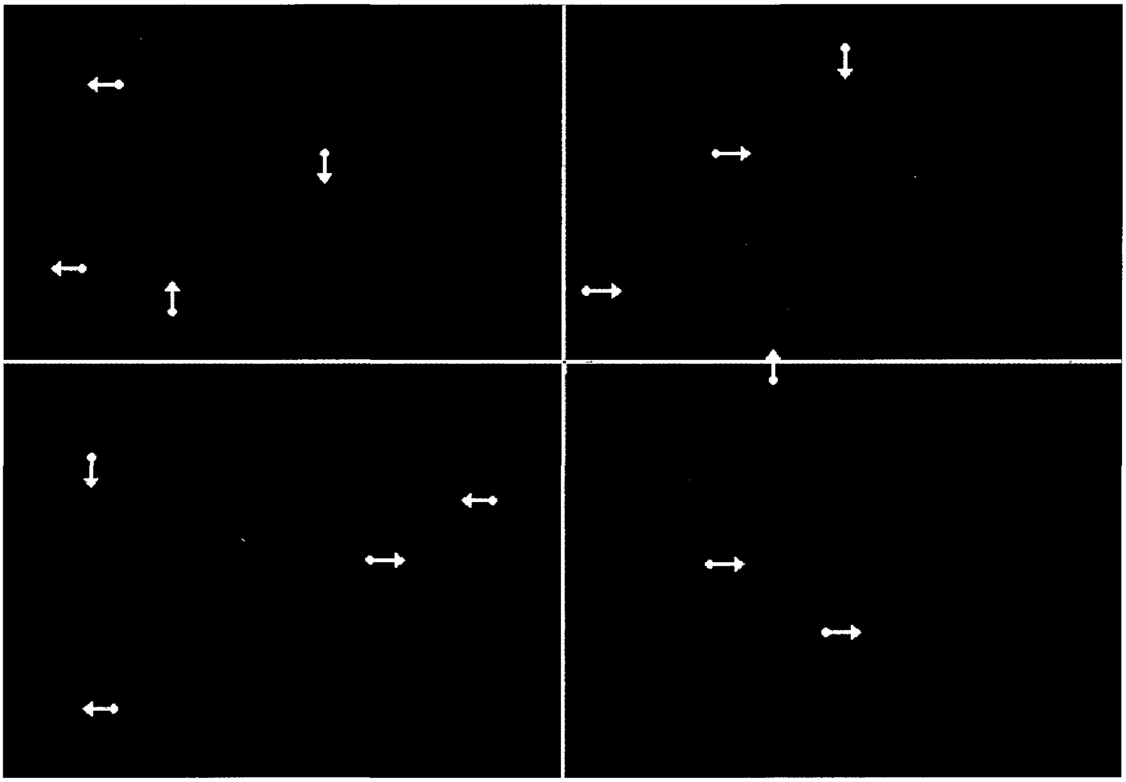

Figure 10. Screenshot of experimental stimuli with arrows present in the recovery phase. Note that in this experiment these arrows only appear in the recovery phase and not in the tracking phase.

Research Design

As is depicted in Figure 11, this experiment implemented a mixed design with one between- subjects variable (occlusion movement, occlusion no movement) and one within-subjects variable that manipulated presentation of direction information in the recovery phase (recovery phase arrow, recovery phase no arrow). A mixed design was employed to minimize the level of fatigue that would occur if the experiment was completely within.

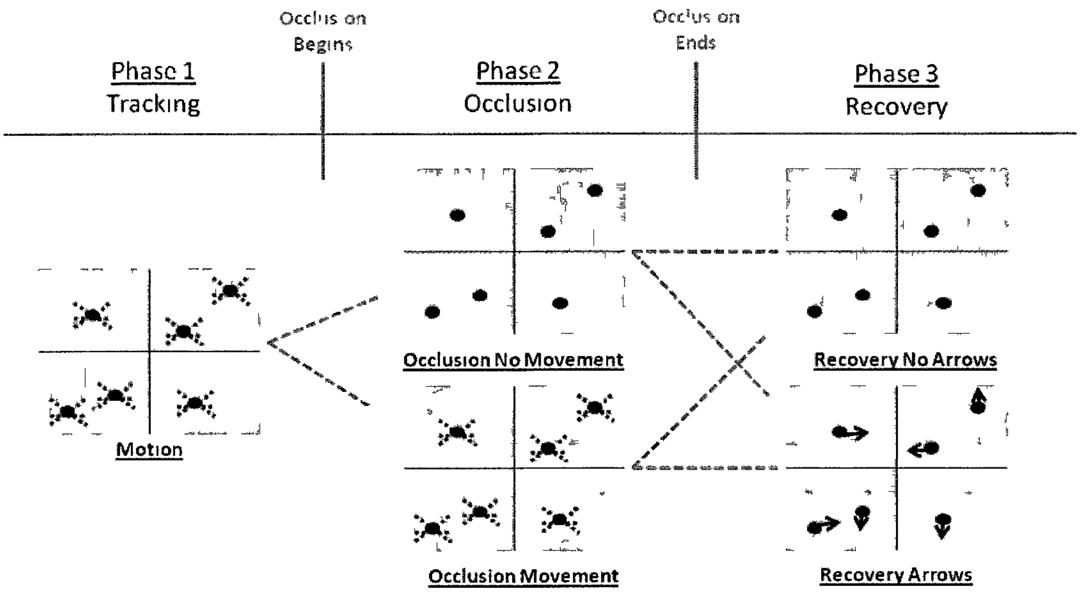

Figure 11 Overview of experimental design for Experiment 2. Targets in the occlusion phase move during the occlusion or remain static. Objects in the recovery phase are presented as static objects or they are presented with arrows to indicate the direction they were moving in the tracking phase. The occlusion and recovery phases are completely crossed. The "CA" labels are not included in the tracking phase of this diagram, but they were present during the actual experiment.

Procedure

Participants were randomly assigned to either the *occlusion movement* or *occlusion no movement* condition. Next, participants proceeded to complete two fully within counterbalanced experimental conditions (*recovery phase arrows* and *recovery phase no arrows*). Participants were instructed to track six "CA" targets for a randomized duration (25-35 seconds) amongst eight distracters. Randomization of tracking time was used to decrease the predictability of occlusion onset. After the tracking phase ended the tracking screen was occluded by a black screen. Participants were instructed to stare straight ahead during the occlusion period. The occlusion period lasted for 30 seconds after which the tracking screen with unlabelled dots reappeared. In the *occlusion no movement* condition, the dots did not change their location during the occlusion and re-appeared in their pre-occlusion locations. In contrast, in the *occlusion movement* condition dots kept moving at the same speed and direction and reappeared in a new position after the occlusion ended. Immediately after the tracking phase, the screen froze and all alphanumeric labels disappeared and arrows pointing in the direction of movement appeared. Participants were then instructed to use the mouse to click on the six "CA" targets. Once a dot was clicked it turned red and could not be un-clicked. After the participant clicked on six targets they were instructed to hit enter to move onto the next trial.

Results

Data cleaning and assumptions.

All dependent variables were checked for outliers, missing data, normality, and homogeneity of variance. The data can be assumed to comply unless otherwise indicated. The assumption of homogeneity of variance was assessed using Levene's test. Based on an assessment of z-scores two extreme scores were found for resumption lag. The outliers were moved within +2 SD of the next most extreme score.

Performance accuracy.

An initial repeated measures analysis on time block was assessed to ensure there was no practice or fatigue effects present in the experiment. No significant differences in performance accuracy between the beginning (trials 1-4), middle (trials 5-8), and end (trials 9-12) were found, $F(2, 18) = 1.24, p = 0.32$. There were also no significant interactions with this variable; therefore the results were collapsed across time block.

Accuracy was analyzed with a 2 Occlusion Motion (occlusion movement versus occlusion no movement) x 2 Direction Cues (recover phase no arrow versus recovery phase arrow) mixed model ANOVA. The results indicated a significant Occlusion Motion x Direction Cues interaction, $F\,(1, 18) = 5.29, p <.05, \eta^2_p = 0\ .23$. The interaction, presented in Figure 12, along with the simple main effect results, suggests that the presence of arrows after the occlusion no movement condition, leads to the same level of performance when there are no arrows. In the occlusion movement condition, the arrows improve performance relative to the no arrow condition. A significant main effect for Direction Cues, $F\,(1, 18) = 4.96, p < 0.05, \eta^2_p = 0.21$ was found, as well as a significant main effect for Occlusion Motion, $F\,(1, 18) = 16.48, p < 0.01, \eta^2_p = 0.48$, was found.

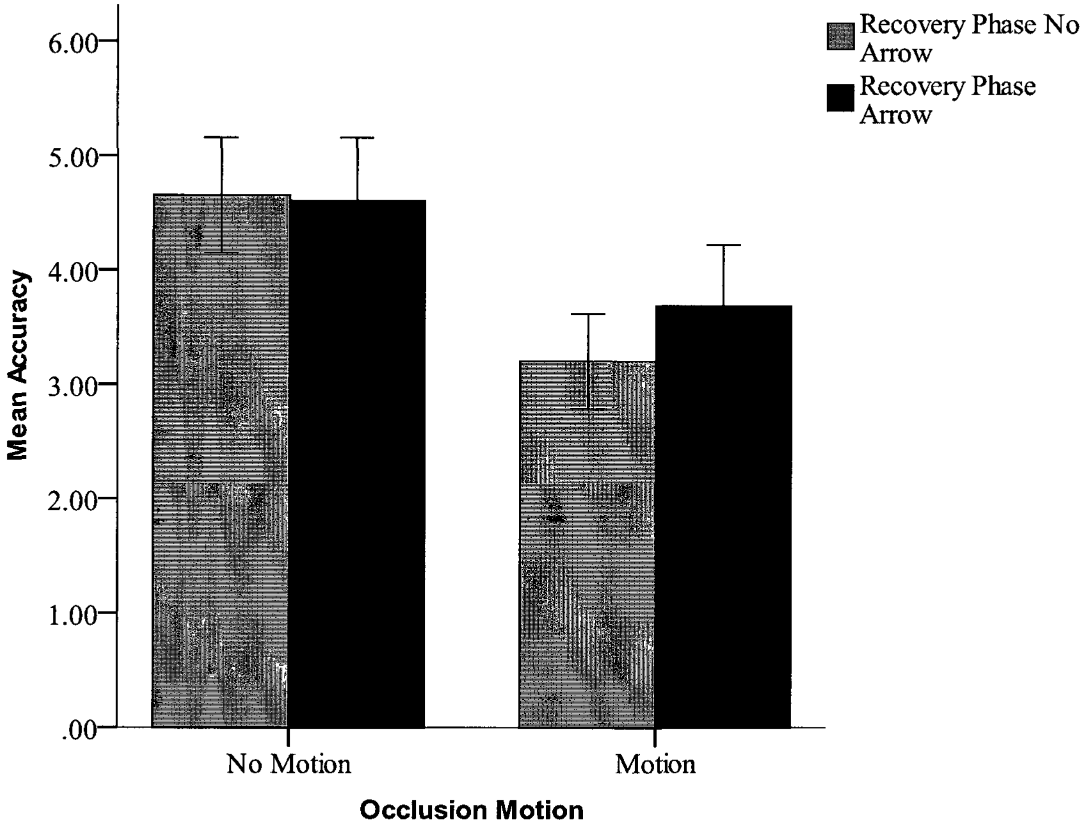

Figure 12. Bar graph with 95% CI's representing the significant Occlusion Motion x Direction Cues interaction effect with mean accuracy as the dependent variable. The interaction suggests that direction information (arrow condition) facilitates target recovery relative to the no arrow conditions when objects are displaced, but the arrow does not facilitate recovery in the occlusion not displaced condition relative to the no arrow condition.

To further investigate the interaction, paired sample t-tests were conducted with a Bonferroni correction. The paired sample t-test revealed significant differences between recovery no arrow and recovery arrow when occlusion motion was presented, t (9) = -3.50, $p < 0.025$. A significant difference between recovery arrow, when there was occlusion movement, and recovery arrow, when no occlusion motion was present, was found t (9) = -2.90, $p < 0.025$. As depicted in Figure 12, the interaction suggests that direction information (arrow condition) facilitates target recovery when objects move during the occlusion, yet the arrow doesn't facilitate recovery when the target does not move during the occlusion relative to the no arrow condition.

Resumption lag.

Resumption lag was measured as the time to first correct click after the occlusion. Only those trials where the first click accurately identified one of the CA targets were included in the analyses. A 2 Occlusion Motion (occlusion no movement, occlusion movement) x 2 Direction Cues (recovery phase arrow, recovery phase no arrow) mixed model ANOVA was run on resumption lag. Contrary to the hypothesis presented above, there was no significant main effect for Direction Cues F (1, 18) = 0.69, p =.80; suggesting that arrows do not add additional processing time. A significant Occlusion Motion x Direction Cues interaction, F (1, 18) = 4.46, p <.05, η^2_p = .20 was found. Further, a significant main effect for the between Occlusion Motion variable was found, F (1, 18) = 18.71, p<.001, η^2_p = .51. The significant main effect for occlusion motion indicates that the time to locate the first target in the occlusion movement condition was significantly longer (M= 5.01, SD= .36) than the occlusion no movement condition (M= 2.78, SD= .42). As can be seen in Figure 13, the significant interaction effect shows that resumption lag was slower when the targets moved during the occlusion in comparison to the arrow condition when there was no movement during the occlusion. It should be noted that this interaction has a small effect size, whereas the main effect for motion occlusion has a stronger effect size. The results should, therefore, be reviewed with this in mind.

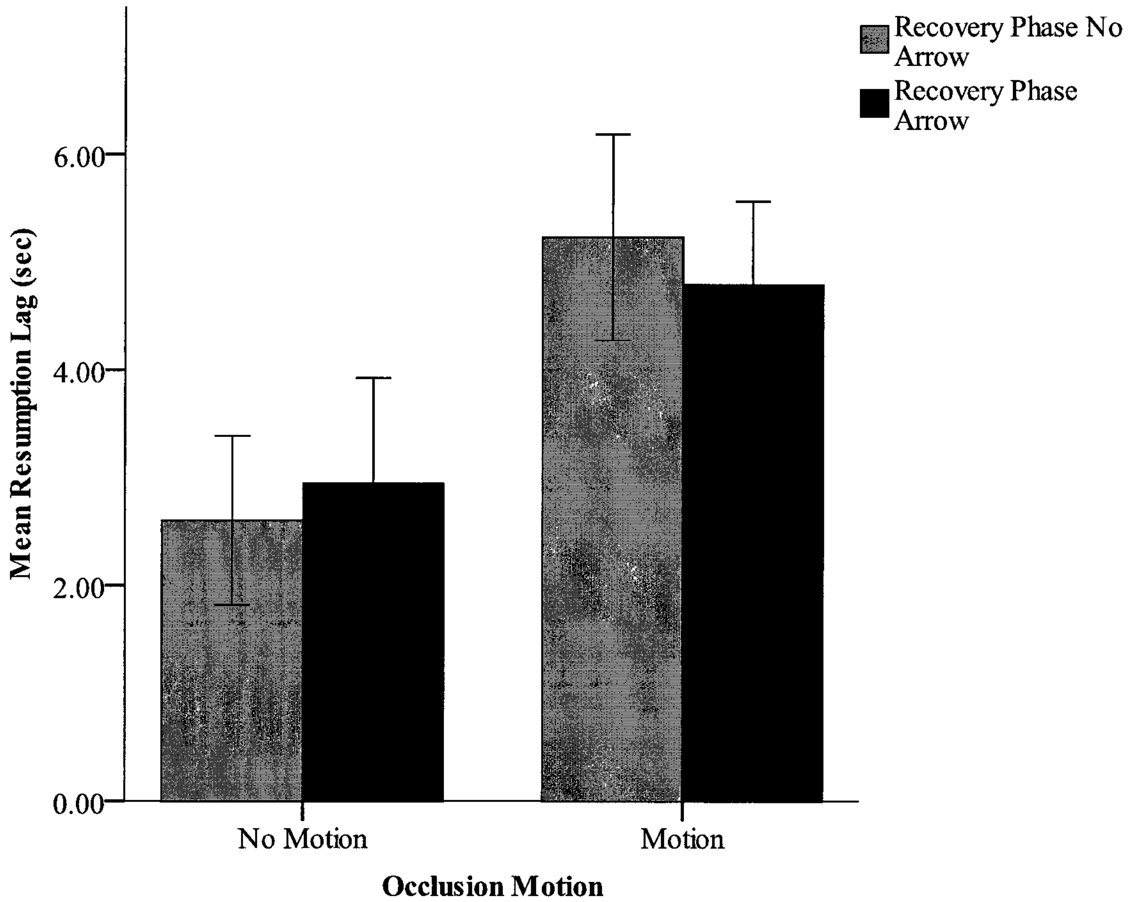

Figure 13. Bar graph with 95% CI's representing the significant Occlusion Motion x Direction Cue interaction effect with resumption lag as the dependent variable.

The significant interaction effect was followed up with a paired samples t-test between arrow and no arrow in the occlusion motion condition. No bonferroni correction was implemented because only one paired samples t-test was completed. No significant difference was found $t\ (9) = -1.38, p = 0.20$. The small effect size and non-significant simple effect present a difficulty in the explanation of this interaction. As such, any conclusions made remain provisional.

Discussion

The objective of Experiment 2 was to examine the effect of recovery phase direction cues (arrows in the absence of motion) on an observer's ability to locate targets after occlusions. The results of the simple main effect analysis for performance accuracy indicate that directional arrows (when compared to no directional arrow) significantly improve performance in recovering targets that move during the occlusion period. This result is similar to the results of Experiment 1 where, much like direction, recovery phase motion facilitated target recovery relative to the no motion condition when targets moved during the occlusion. Overall, the results suggest that observers encode direction information (and motion information) while trying to recover targets which have moved during the occlusion.

Newell, Wallraven, and Huber (2004) found that direction information is encoded in the same way salient features such as colour and shape are encoded. They argued that spatiotemporal parameters are stored in working memory (WM). Such results are also in-line with Suganuma and Yokosawa (2004), who found that greater differences in the trajectory of targets and distracters results in more accurate target recovery in MOT. Overall, the significant recovery phase by occlusion phase accuracy results of this experiment provide evidence that multiple-object tracking can utilize direction information without motion to recover targets. Along with support from previous research (i.e., Fencsik, Urrea, Place, Wolfe, & Horowitz , 2006), it is reasonable to state that direction information is as valuable as location and motion information in MOT.

In light of these results, it is important to revisit the results of Experiment 1. Although Experiment 1 suggests that motion information is encoded and used in target recovery, it is possible that it is not motion as a whole that is stored, but rather direction information. If motion as a whole was required, then direction on its own should not have facilitated target recovery in the same manner as motion. Based on the performance accuracy results, it appears as though direction information on its own is able to activate target recovery in situations where targets have continued to move during the occlusions. Since direction is inherent in motion, it is possible that observers primarily encoded direction information in experiment 1. This would explain why the performance accuracy results of Experiment 1 and Experiment 2 are similar. Although speculative, the occlusion phase by recovery phase interaction accuracy results along with the strong main effect for occlusion motion resumption lag suggest that it is unlikely that a completely on-line form of tracking occurs during occlusions. It seems more likely that direction information along with location information is stored and used to perform an off-line extrapolation to recover targets. Given the last known location, in conjunction with direction, it is possible that observers are able to estimate a probable extrapolated location for the targets after occlusions, if they are provided with some form of recovery phase spatiotemporal information.

This trend of results suggests that objects are not tracked in an on-line manner. This is supported by both the performance accuracy and the occlusion motion main effect resumption lag. If on-line tracking was taking place, one would have expected to find a significantly faster resumption lag for the conditions where the targets moved during the occlusion since the recovery phase locations of the targets should match the mental representation of the extrapolated targets. This is, however, not the case; instead the resumption lag is fastest for the targets which did not move during the occlusion.

One unique aspect of the current experiment is the opportunity for a partial encoding specificity, wherein the encoding and recovery phase both provide direction information to the observer. Given that motion was present in the tracking phase, it is possible that the presence of motion provided some form of trajectory trace (or momentum) which in conjunction with recovery arrows was enough to help in the backward extrapolation of targets. Perhaps arrows are enough to elicit recovery, but the momentum information gained in the tracking phase is required to complete the recovery. In order to get a clearer picture of what information is encoded and used in recovery, the following experiment isolated and crossed all spatiotemporal information in the encoding and recovery phase.

Experiment 3

Multiple-object tracking research tells us that attention and memory mechanisms are employed in the maintenance and recovery of target information. However, the exact encoding and retrieval processes involved in tracking and recovery are unknown. As an extension of Experiment 1 and 2, uncovering what spatiotemporal information (e.g. direction, location, and motion) is encoded during tracking and used during the recovery phase was a main objective of Experiment 3.

Results from the previous two studies provided valuable information about the use of spatiotemporal information, specifically direction and motion, during the recovery of targets in situations where targets moved during occlusions. Overall, the results of Experiment 1 and 2 suggest that something more than location is encoded and used in MOT recovery. But, the use and importance of each piece of spatiotemporal information is still unknown. It is possible that only direction information is extracted from motion, and that only direction information is encoded and used to facilitate recovery. On the other hand, perhaps motion adds something much more than direction to MOT. In both of the above presented experiments, the tracking phase presented the observer with objects that were moving. Although motion is essential to MOT, it does confound the results when one is trying to isolate the impact and encoding of location, direction, and motion. As such, the main approach of this experiment was to fully cross the information presented in the encoding and recovery phase as a way to tease apart which information is most valuable to MOT.

Up to this point, the results of the current experiments have suggested that observers encode location information, in addition to direction and motion information. Furthermore, the results of the prior two studies imply the use of off-line tracking, which contrary to Keane and Pylyshyn (2006) and Oinonen et al. (2009), strongly suggests that spatiotemporal information is encoded and used in the recovery of targets. On their own, these two results are unique and imply a new form of off-line tracking, which utilizes spatiotemporal information via backward extrapolation. What is unclear at this point is whether observers are able to simply use direction and location information, in the absence of motion, to make a general assessment as to the new location of the target after the occlusion. Both Experiment 1 and 2 always presented motion information (for obvious reasons) during the tracking phase, which has prevented me from directly answering this question. It is likely that the motion information presented in the tracking screen has an impact on recovery. It is, therefore, hypothesized that if the off-line recovery of the target is dependent only on location and direction information, then the presentation of an arrow during the tracking screen should lead to performance that was in Experiment 2 above. Conversely, if conditions with motion result in improved performance, relative to those with only direction information, this would imply that target recovery is dependent upon spatiotemporal information that is beyond just location and direction. By isolating various spatiotemporal properties in the tracking and recovery phase, I was able to uncover not only what information was encoded, but how this information was used in target recovery.

It should be noted that the occlusion no movement condition was dropped from this experiment because the focus of this experiment was to uncover the mechanism by which targets are recovered when they moved during occlusions. Further to that, the prior two experiments provide evidence to suggest that location information was the primary piece of information used to recover targets that did not move during the occlusion. As such, there was no reason to continue on with the occlusion no-movement condition.

Method

Participants

Thirty undergraduate students (20 females; 10 males) from Carleton University participated in the study. All participants were right handed and had normal or corrected-to-normal vision. Their ages ranged from 18 to 60 ($M = 22.43$, $SD = 8.41$). Participants that took part in experiment 1 and experiment 2 were not eligible to participate in this experiment.

Materials

This experiment employed the same MOT paradigm as discussed in the general methods section. In conditions requiring direction cues, such as arrow and arrow + motion, a set of arrows were presented. The arrows were located at the centre of the dot. The arrows were 3 pixels in thickness and 15 pixels in length.

Research Design

This experiment employed a mixed design which is visually represented in Figure 14. The between-subjects variable known as tracking phase manipulated the following 4 pieces of information:

1. Arrow (no motion)
2. Motion (no arrow)
3. Arrow with Motion
4. None (static dot)

The within-subjects variable known as recovery phase manipulated the following 3 pieces of information:

1. Arrow
2. Motion
3. Arrow with Motion

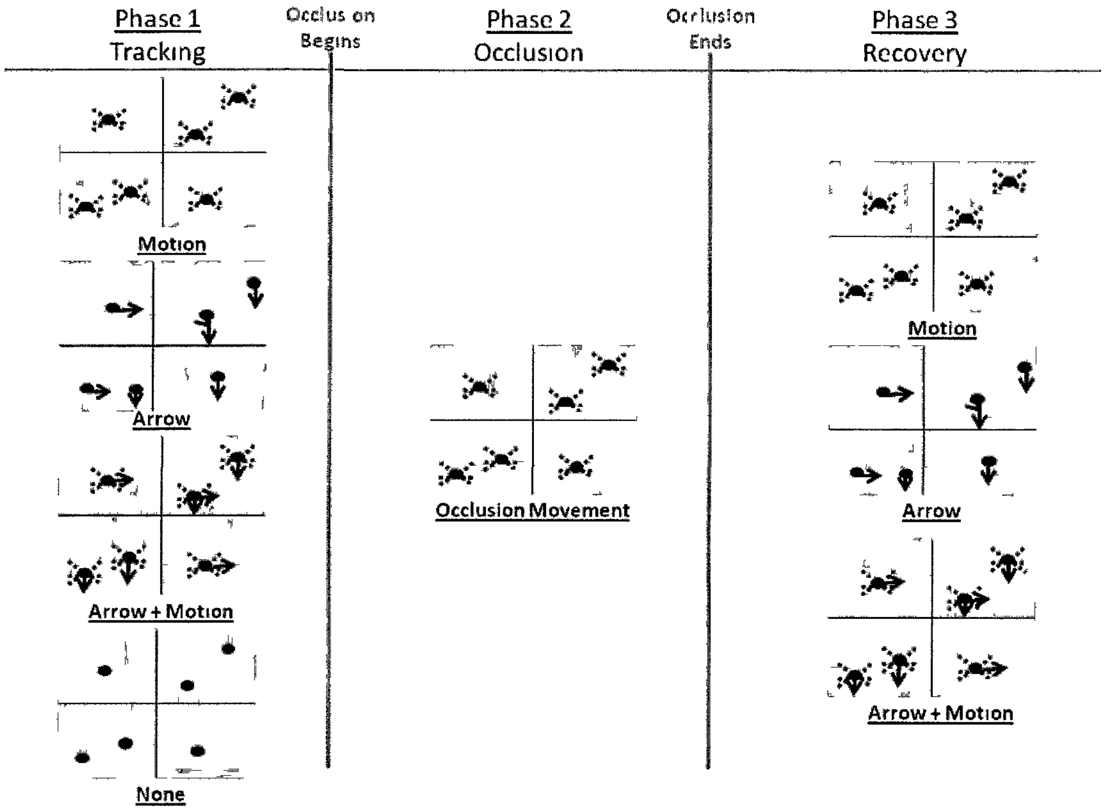

Figure 14 Overview of experimental design for Experiment 3. All of the between and within subjects factors are fully crossed with each other. Objects in the tracking phase have arrows, motion, motion with arrows, or no information. Targets in the occlusion phase always move. The "CA" labels are not included in the tracking phase of this diagram, but they were present during the actual experiment.

Procedure

Participants were randomly assigned to one of the 4 tracking screen conditions (motion, arrows, motion with arrows, none). Next participants proceeded to complete three fully within counterbalanced recovery screen conditions (arrows, motion, and motion with arrows). The trials for each of these conditions were blocked. Participants were instructed to track six "CA" targets for a randomized duration (25-35 seconds) amongst eight distracters. Randomization of tracking time was used to decrease the predictability of occlusion onset. After the tracking phase ended the tracking screen was occluded by a black screen. Participants were instructed to stare straight ahead during the occlusion period. The occlusion period lasted for 30 seconds after which the tracking screen with unlabelled dots reappeared. In all cases the dots moved during the occlusion. Immediately after the tracking phase all alphanumeric labels disappeared. Depending on the condition the dots continued moving, were static but had arrows, or continued moving plus had arrows. Participants were then instructed to use the mouse to click on the six "CA" targets. Once a dot was clicked it turned red and could not be un-clicked. After the participants clicked on six targets they were instructed to hit enter to move onto the next trial.

Results

Data cleaning and assumptions.

All dependent variables were checked for outliers, missing data, normality, and homogeneity of variance. The data can be assumed to comply unless otherwise indicated. The assumption of homogeneity of variance was assessed using Levene's test.

Performance accuracy.

An initial analysis on time block was run to ensure that there was no practice or fatigue effects present in the experiment. No significant differences in performance accuracy between the beginning (trials 1-4), middle (trials 5-8), and end (trials 9-12) were found $F(2, 162) = 2.85$, $p = 0.08$. Since there were no significant interactions with time block and any of the other variables all following analyses were collapsed across time block.

Accuracy was analyzed with a 4 Tracking phase (Arrow; Motion; Motion with Arrows; None) x 3 Recovery Phase (Arrow; Motion; Arrows with Motion) mixed model ANOVA. The results indicated a significant Tracking phase x Recovery Phase interaction, F (6, 81) = 2.49, $p < 0.05$, η^2_p=0.16. A significant main effect for Tracking phase, F (3, 81) = 27.02, $p < 0.001$, η^2_p = 0.50, was found, but the main effect for Recovery Phase was not significant F (2, 27) = 1.61, $p = 0.22$. Although the interaction is significant, it should be noted that the effect size is relatively small in comparison to the significant main effect of tracking phase. As such, both the interaction and the main effect will be discussed in detail below.

Main effect of tracking phase.

Although there was a significant interaction effect, it was a notably weak effect. On the other hand, a moderate main effect for tracking phase was found (η^2_p= 0.50). As such, the following analyses will be based on the main effect for tracking phase information. As can be seen in Figure 15, it appears as though the presentation of spatiotemporal information aids in the recovery of targets more so than the presentation of static objects (none condition).

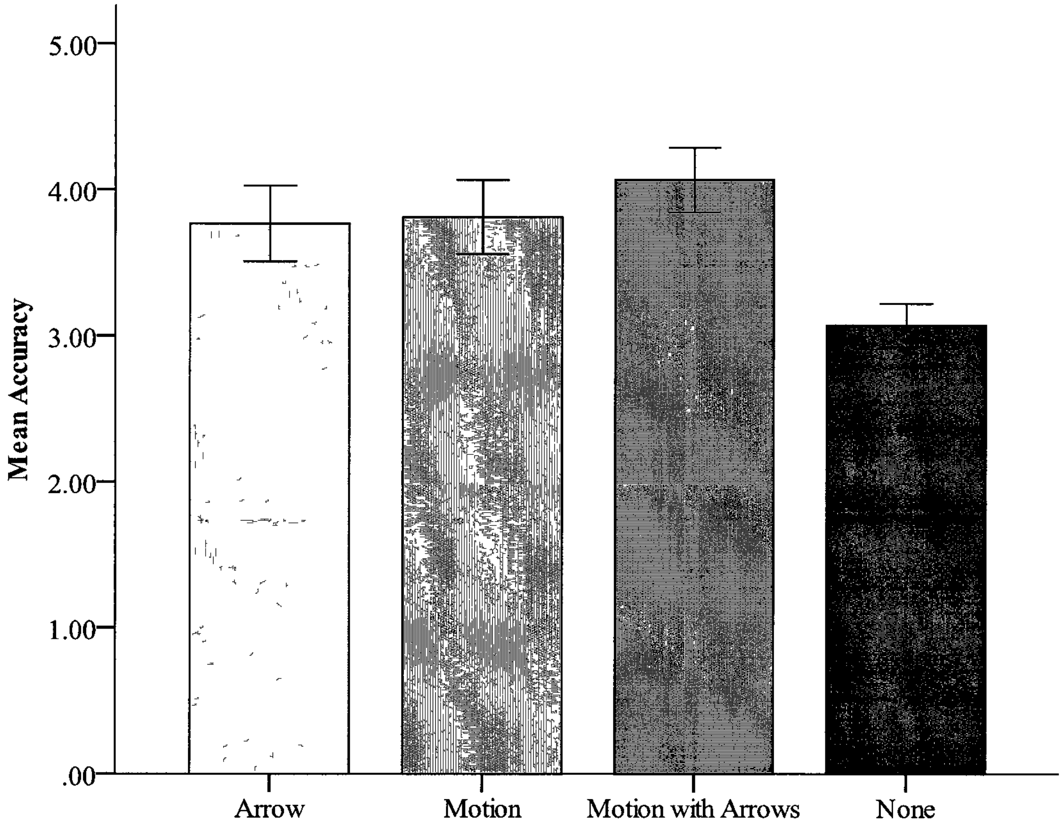

Figure 15. Bar graph representing the impact of tracking phase information on performance accuracy. 95% CI's are depicted.

As can be seen by the 95% CI's presented in the graph, it appears as though the presence of spatiotemporal information helps facilitate target recovery. In order to investigate the differences between the other tracking phases, paired samples t-tests were completed. The first paired samples t-test was completed to determine if there were differences between Arrow and Motion with Arrow, as well as to determine if there were differences between Motion and Arrow with Motion. The results of the paired samples t-test revealed a significant difference between Arrow in comparison to Motion with Arrows, $t\ (29) = -2.45, p<.05$, where Arrows alone had lower accuracy than Motion with

Arrows. There was, however, no significant difference between Motion and the Motion with Arrow condition, $t\ (29) = 1.36$, $p = 0.18$.

These results suggest that observers have the propensity to assess where targets will be located, as long as there is spatiotemporal information. It should be noted that while direction information alone results in performance which is much better than the presentation of static objects in the tracking phase, motion with arrow information still seems to add something unique to the tracking phase. Interestingly, no difference was found between motion and arrows. Taken together, this result suggests that while motion with arrows is superior to just arrows and location (static dot), observers are still able to relocate the location of displaced targets using just location and direction cues in the tracking screen. Further, the lack of a significant recovery screen main effect compliments the results of Experiment 1 and 2, wherein accuracy was similar when there were arrows or motion present in the recovery screen. Overall, these results suggest that spatiotemporal information is encoded and used to facilitate recovery. Unfortunately, the results of this experiment do not provide a clear picture as to which piece of spatiotemporal information is the "most important". It does, however, seem as though more spatiotemporal information is better in helping observers encode information.

Tracking phase x recovery phase interaction effect.

The presentation of spatiotemporal information (arrows, motion, and motion with arrows) in the tracking phase facilitates performance accuracy. That is, performance is not as good when no spatiotemporal information is presented in the tracking phase, as compared to conditions where there is spatiotemporal information. As can be seen in Figure 16, the most notable trend in the graph occurs when motion information is present in both the tracking and recovery phase. The graph indicates that the match between recovery and tracking phase motion, yields more accurate target recovery. Interestingly, it does not seem as though tracking phase motion results in better performance across the other recovery phase conditions (motion; motion with arrows). This result does point to a possible encoding specificity effect, yet this is not the case for arrow and motion with arrow conditions. Given that this interaction is complex, and the exact trends are not particularly clear, a series of simple effects analyses and interaction contrasts will be performed.

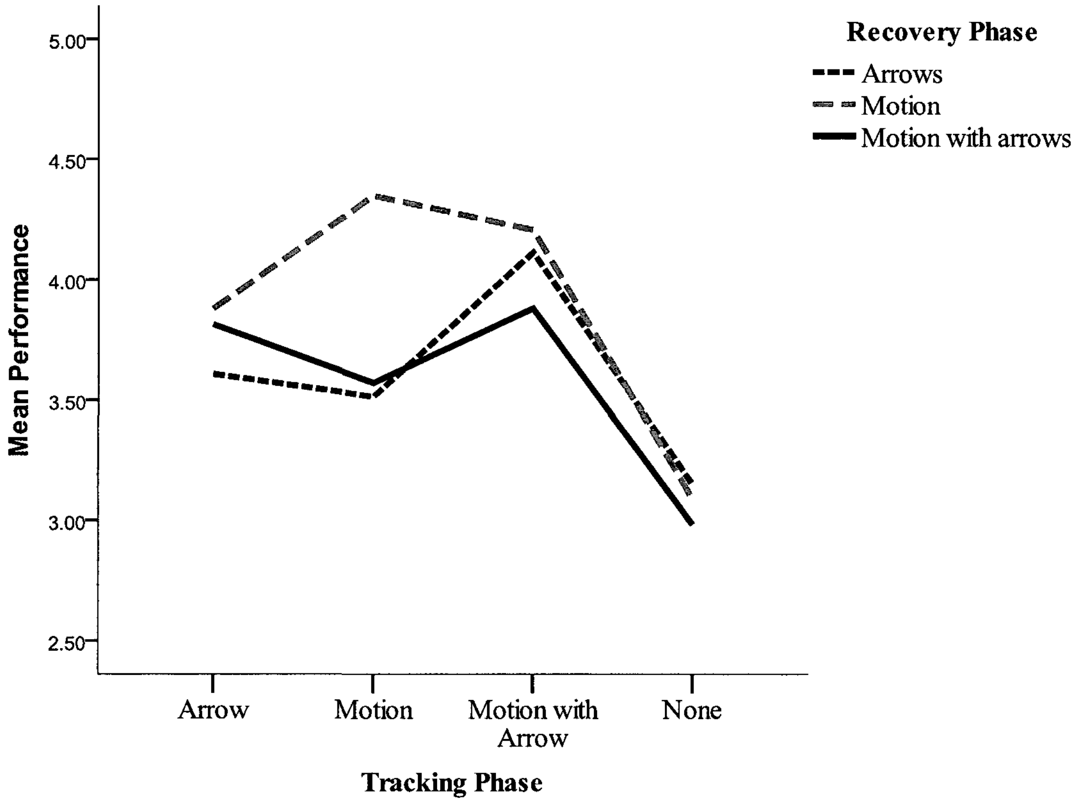

Figure 16. Significant Tracking phase x Recovery Phase interaction effect depicting overall better performance when the tracking phase and recovery phase both contain motion. (Note: although a bar graph is typically more appropriate, the line graph more clearly depicted this particular interaction).

The significant interaction was assessed by a simple effects analysis of the between-subjects factor (recovery phase), at each level of the within-subjects factor (tracking phase) (Page, Braver, & MacKinnon, 2003). The simple effects analysis, revealed a significant simple effect for Motion in the within-subjects condition, $F(2, 27) = 6.44, p < 0.01$. The presentation of motion in both the tracking and recovery screen resulted in better performance, when compared to conditions with arrows and arrows with motion in the recovery phase. No significant simple effects were found for Arrow, $F(2, 27) = 0.40$, $p = 0.68$; Motion with Arrows, $F(2, 27) = 0.78$, $p = 0.47$; or None $F(2, 27) = 0.44$, $p = 0.65$.

Results suggest that a match between tracking and recovery phase motion facilitates target recovery. Visual analyses of the differences, as seen in Figure 16, indicate a lack of the expected encoding specificity effect for arrow-to-arrow, and arrow with motion-to-arrow. This result could imply that there is more than just encoding specificity at play. In fact, it may suggest that there is something unique about the motion-to-motion combination, which is not present in the other combinations. Although, a motion-to-motion match produces the highest level of performance, the results do not depict overall motion superiority. This is especially odd given that the motion with arrow condition always contains motion, which would match the motion presented in the tracking phase. In fact, the presence of motion or arrow alone in the tracking phase, and motion with arrow in the recovery phase is associated with some of the poorest performance.

Resumption lag.

An initial analysis on time block was assessed to ensure there was no practice or fatigue effects present in the experiment. No significant differences in performance accuracy between the beginning (trials 1-4), middle (trials 5-8), and end (trials 9-12) were found $F(2, 162) = 0.98$, $p = 0.38$. Since there were no significant interactions with time block and any of the other variables, all following analyses were collapsed across time block.

Resumption lag was measured as the time to first click at the end of the occlusion. Only those trials where the first click accurately identified one of the CA targets were included in the analyses. Resumption lag was analyzed with a 4 Tracking phase (Arrow; Motion; Motion with Arrow; None) x 3 Recovery Phase (Arrows: Motion; Motion with Arrows) mixed model ANOVA. A significant Tracking phase x Recovery Phase interaction was found, $F\,(6, 81) = 2.62, p<.05, \eta^2_p = .16$. This interaction can be seen in Figure 17. Further, a significant main effect of Tracking phase was found, $F\,(3, 81) = 3.69, p < 0.05, \eta^2_p = 0.12$, but no significant main effect for Recovery Phase was found, $F\,(2, 27) = 2.47, p = 0.10, \eta^2_p = 0.16$.

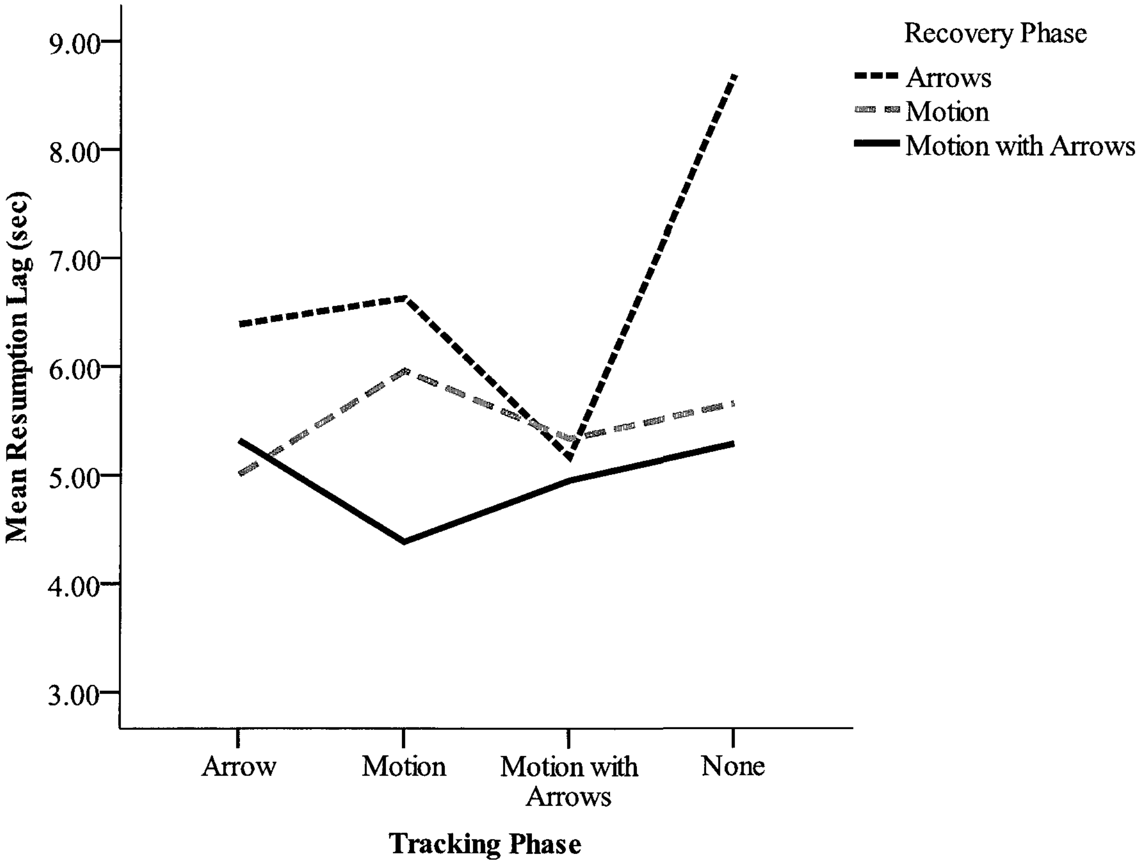

Figure 17. Interaction graph for Tracking phase x Recovery Phase with resumption lag as the dependent variable.

Simple effects.

The significant interaction was assessed with simple effects of the between-subjects factor (Tracking phase), at each level of the within- subjects factor (Recovery Phase) (Page, Braver, MacKinnon, 2003). The simple effects analysis revealed a significant simple effect of the None tracking phase, $F\,(2, 27) = 3.34, p = 0.05$. As evidenced by the graph, the resumption lag is significantly slower when there is an arrow present in the recovery screen, than when there is motion or motion with arrows. This result suggests that with a lack of tracking phase information, the presentation of an arrow during the recovery phase significant slows the recovery of targets. On the other hand, motion and motion with arrows, when presented in the recovery phase, do not demand the same level of attentive processing allowing for a quicker recovery of the targets.

Discussion

The results of this experiment highlight the importance of spatiotemporal information. The presentation of spatiotemporal information in the tracking phase, led to better performance than conditions with only location information (static dot condition). Although the results do not allow for conclusive statements about what information is encoded, the results do indicate that more than just location and direction information is encoded in MOT tasks. Even the presentation of arrows in the tracking phase, in the absence of motion, facilitates target recovery significantly better than location alone (static dot). Although the simple main effects suggest motion and arrows were not significantly different, there was significantly better performance when observers were presented with motion with arrows in comparison to just arrows. This result suggests that there is something more in the motion with arrows condition than is present in the motion only condition, which was not significantly different than arrows. Perhaps the explicit presentation of arrows, which is not present in the motion only condition, helps facilitate direction encoding. As such, it is possible that extracting direction information from moving targets is effortful so the presentation of both motion and arrows together facilitates and makes this easier.

As was mentioned in the introduction, off-line theories of MOT suggest a saliency for location information which is encoded and used in MOT. A number of researchers suggest that the last known pre-occlusion location drives target recovery in some ad hoc manner (e.g. Sears & Pylyshyn, 2000; Pylyshyn & Storm, 1988). Further to that, these researchers indicate that tracking is not driven by high-level cognitive processing. The problem is that processing of direction and motion information is not accounted for by MOT theories. In contrast, the results of the current experiment suggest that spatiotemporal information, other than location information, is encoded and used in the recovery of targets in MOT.

General Discussion

Predictions about attentional and cognitive processing involved in tracking dynamic objects abound in the literature. For instance, there are claims and supporting evidence to suggest that tracking is an automatic process, dependent on early visual processes (i.e., Bahrami, 2003; Pylyshyn, & Storm, 1988). Such theories point to a saliency of location information, whereas featural or identity based information (colour, shape, direction) is largely ignored. On the other hand, Yantis (1992) and Kahneman, Treisman, & Gibbs (1992), suggest an important role for directed attention and cognitive processing during tracking tasks. Kahneman et al. suggest that object files store characteristics such as motion, colour, and identity information during tracking. In order to understand and uncover the encoding of spatiotemporal information, three experiments were conducted. These experiments investigated the isolated and combined impact of motion and directional cues (arrows) during the tracking phase (pre-occlusion), and the recovery stage (post-occlusion) on the recovery of targets after occlusions. Of particular interest, was whether motion and direction information (depicted by arrows) in the tracking and recovery phase aided in the recovery of occluded and displaced targets. This was investigated by looking at the differences in performance, when motion and arrows during the tracking phase and recovery phase were manipulated. This novel approach to studying MOT encoding differs from commonly used methods, in that traditional MOT paradigms almost always present motion in the tracking phase and no spatiotemporal information in the recovery phase.

The first experiment presented motion information in both the tracking and recovery phase in order to investigate the impact of motion information on target recovery. Furthermore, this experiment assessed the impact of encoding specificity between the tracking and recovery phase. It was hypothesized that if motion information was encoded during the tracking phase, then the presence of motion after the occlusion would facilitate the recovery of objects after the occlusion (Matthews, Benjamin, & Osborne, 2007; Tulving & Thomson, 1973). It was also hypothesized that on-line tracking mechanisms would find the presence of motion helpful in the recovery of targets, given that continual motion after the occlusion would match the location of the target during on-line tracking. As such, there should be a match between the "mentally tracked" position of the targets and their actual physical location making the targets easily recoverable. However, the resumption lag results did not support this. Instead, resumption lag shows that targets which reappear in their prior locations have a quicker resumption lag, suggesting that location information is stored in memory as opposed to suggesting that targets are mentally tracked. The accuracy results were also higher when targets reappeared in their prior locations. Thus, if mental representations of moving objects are dynamic, as is suggested by theories of on-line tracking and representational momentum, then it cannot account for the findings of the first experiment. It seems that the off-line hypothesis with location encoding can best account for these results.

In order to fully understand what spatiotemporal properties are encoded, it was essential to isolate direction from motion information and investigate the isolated impact on target recovery. Experiment 2 was identical to Experiment 1, except that arrow information was presented in the recovery phase instead of motion. The manipulation of recovery phase spatiotemporal information was used to investigate the impact and encoding of direction information by itself in multiple object tracking. Given that Experiment 1 results were better accounted for by the off-line hypothesis, it was hypothesized that direction information would provide enough information to make the off-line target relocation. The results of Experiment 2 were in line with the Experiment 1 results where, much like direction, recovery phase motion facilitated target recovery when targets moved during the occlusion. It was concluded that observers encode and differentiate direction information when trying to recover targets, which have moved during the occlusion. Again the results of the experiment suggested that location information, along with direction information, may be enough to facilitate recovery of targets that moved during an occlusion.

Experiment 3 fully crossed motion, arrows, and motion with arrow conditions in both the encoding and recovery phases to investigate the impact of isolating and combining cues. The aim of this experiment was to provide a clearer understanding of tracking phase encoding, and the use of this encoded information (off-line or on-line) in the recovery phase. The results of this experiment found that spatiotemporal information in the tracking phase was beneficial in accurately recovering targets. The tracking phase by recovery phase interaction results point to a superiority of motion-to-motion encoding specificity. This suggests that there is something more than basic location and direction encoding involved in the tracking and recovery phase. At least, it seems as though the presence of motion, in both recovery and tracking phases, aid in the recovery of targets. The results of this experiment suggest that although direction and location are vital to the recovery of targets, there is something more to motion than just these components. Seemingly, motion is more than the sum of its parts.

Theoretical Account

Off-line backward extrapolation.

The majority of MOT experiments provide support to location encoding (off-line), while ignoring on-line motion or direction encoding (Pylyshyn & Storm, 1988; Pylyshyn, 2004; Keane & Pylyshyn, 2006; Oinonen, Oksama, Rantanen & Hyönä, 2009). It seems intuitive that one would need to encode the direction of a target in order to recover it, yet previous research lacks support for encoding anything more than location information. Like previous research, the results of this thesis support the use of an off-line encoding mechanism which is used in the recovery of targets after occlusions. Unlike the results of previous research, the current experiments suggest that motion, direction, and location encoding facilitate recovery of targets. As mentioned above, these results point toward a new form of off-line tracking that I have named backward extrapolation.

A comparison of expected results with on-line tracking and backward extrapolation are presented in Figure 18 and Figure 19. Figure 18 depicts the expected results when on-line tracking is in-play. This figure describes the process of target recovery in a location based off-line hypothesis, with no movement during the occlusion. The top panel represents the no recovery motion condition, in which the expected location of the target based on location encoding is supported. The bottom panel represents the recovery motion condition, in which location encoding expectations are still supported because the targets pre-occlusion and post-occlusion locations are the same. The two diagrams together show what is likely happening when there is no movement during occlusion (Figure 18), in contrast to when there is movement during occlusion (Figure 19). Since motion resumption does not impact the location encoding theory (when there is no occlusion motion), there are no differences between these conditions.

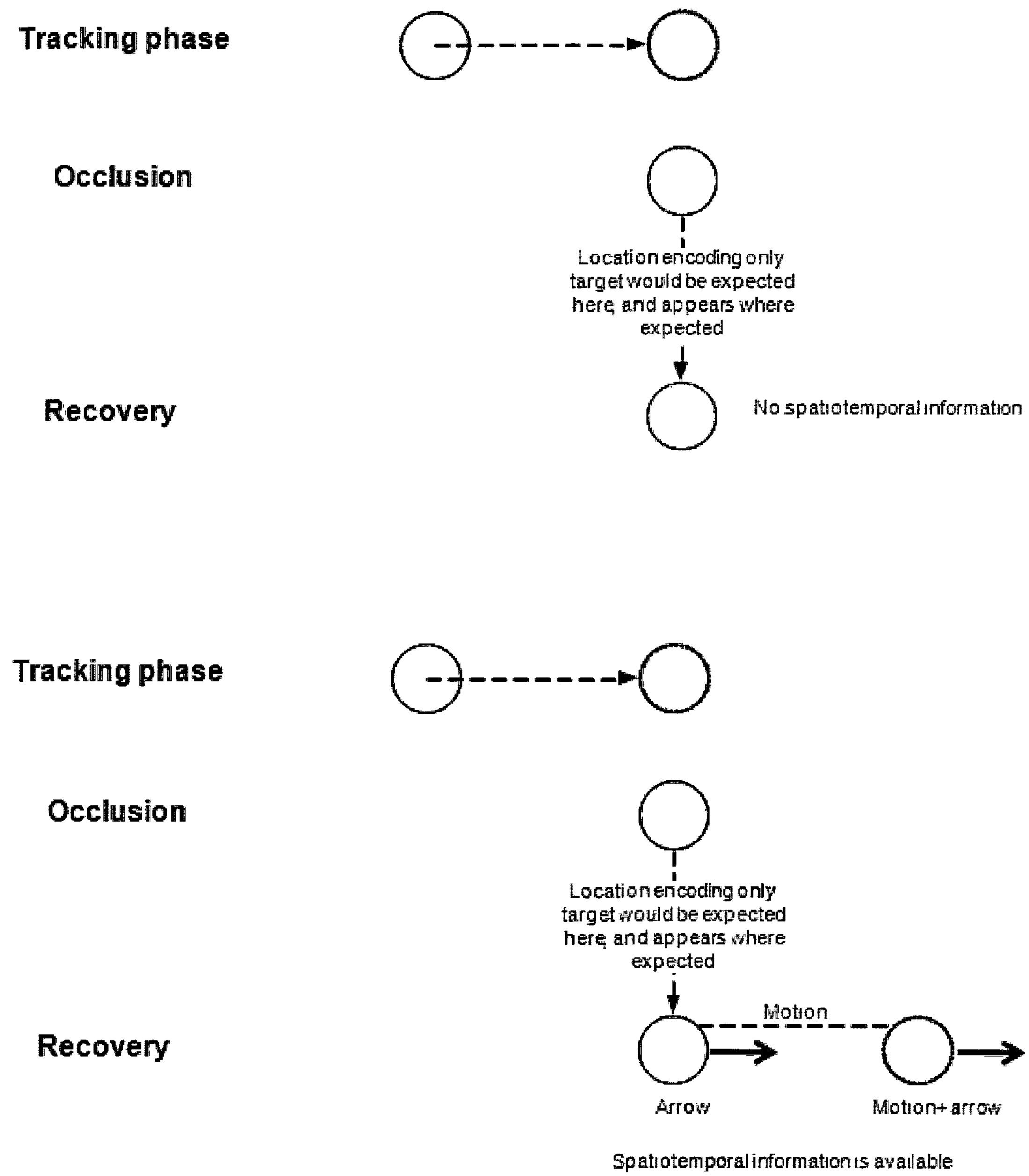

Figure 18. Diagram of target recovery for a no occlusion motion condition.

The spatiotemporal backward extrapolation hypothesis of MOT, as can be seen in Figure 19, suggests that observers perform an off-line type of extrapolation to re-locate targets with the use of location and all other available spatiotemporal information (motion or direction). The top portion represents the no recovery motion condition. In this case, the expected location of the target based on location encoding is not supported. Performance is degraded, because there is no recovery phase spatiotemporal information to determine whether the object is a target. The second portion of the diagram represents the recovery motion condition. Here, the object moves during the recovery stage. Performance in this condition is actually better than the performance in conditions without recovery motion or direction, because the observer is able to use the spatiotemporal motion information to "fill-in-the-blanks" and determine whether the object is a target or not.

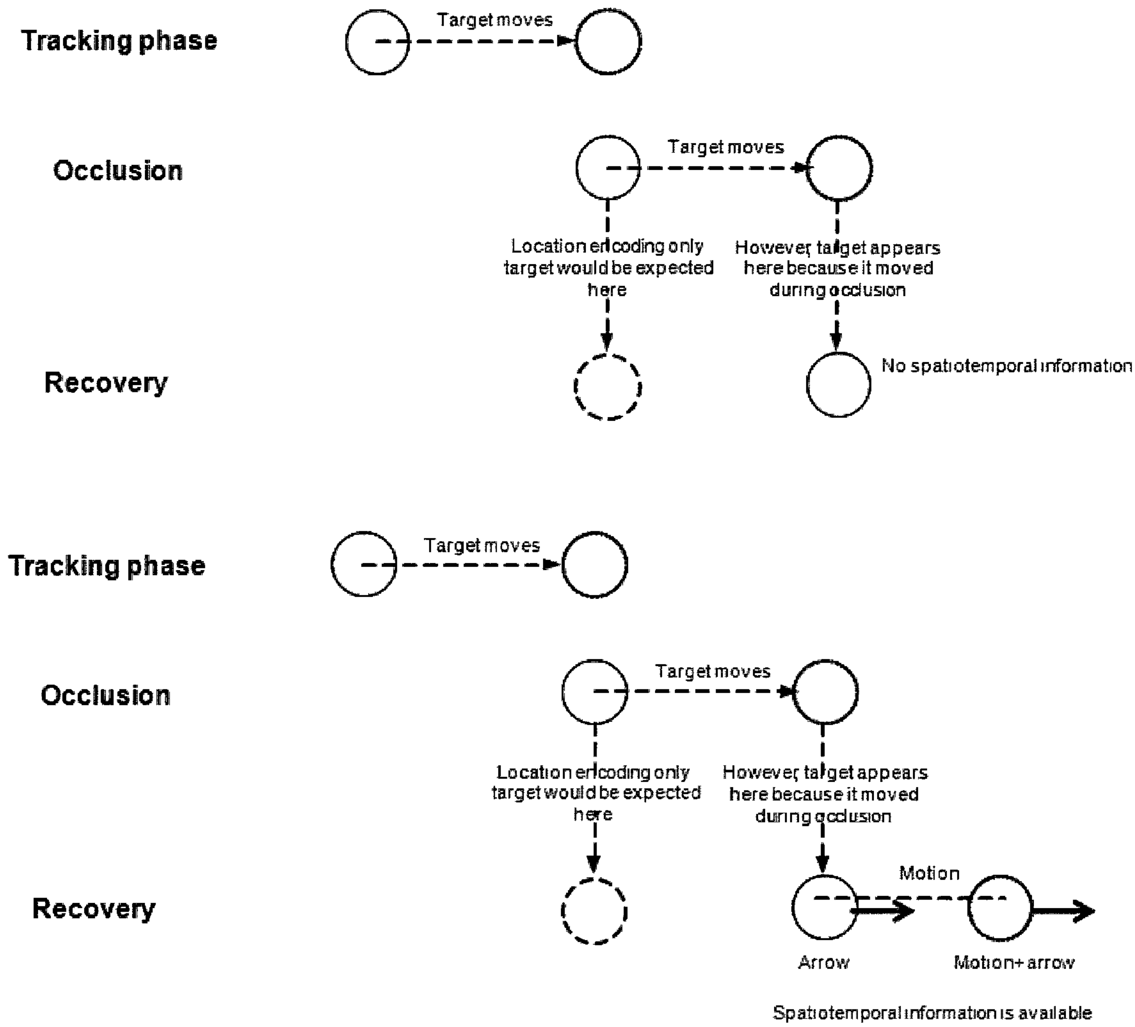

Figure 19. Diagram of target recovery for the occlusion motion, direction or direction + arrow recovery phase condition.

The last known location could be used in conjunction with motion and/or direction to estimate a probable extrapolated location of the targets after occlusions. As accuracy for locating the targets seems to increase when recovery phase spatiotemporal information is present, it is believed that recovery phase spatiotemporal information reactivates prior encoded and stored spatiotemporal information (location, direction, motion) allowing for a more accurate recovery. But, it is not enough that direction and/or motion are encoded;

spatiotemporal information also needs to be activated in the recovery phase to facilitate recovery. This suggests that at least partial encoding specificity is required in the complete recovery of spatiotemporal information.

Role of memory in multiple-object tracking.

It should be noted that the occlusion length used in this thesis extends beyond the capacity limitations of STM (18-20 sec) without some form of rehearsal. It was hypothesized above, that on-line tracking of targets would sustain target motion information in STM by mentally tracking these targets; creating a form of rehearsal. Overall, the results of the current experiments suggest that observers use an off-line mechanism to recover targets. As such, I would like to revisit the use of STM in MOT. Although the current experiments do not provide explicit evidence as to the memory mechanisms used in MOT, I do feel it is necessary to review and integrate the literature within the framework of the current results. The results of the current thesis suggest that spatiotemporal information is important for target recovery. So, where is it that observers are storing spatiotemporal information? It is unlikely that spatiotemporal information is actively rehearsed during the occlusion, thus eliminating STM. As such, there is really only one storage capacity to consider: long term memory (LTM). The only known MOT theory that speaks of LTM storage is Oksama and Hyona's (2008) model of multiple identity tracking (MIT). Although the paradigm they implement in their experiments requires identity tracking, I propose the structure of their paradigm to be similar enough to the current experiment to warrant discussion.

One of the basic tenets of their theory is that LTM representations are used to form "bindings". They also suggest that "spatial indexes" are temporarily stored in VSTM.

These "indexes" allow updating of target locations as they move during the tracking phase. With relation to my current findings, it is possible that the same mechanisms are in play. Figure 20 attempts to display the relationship between encoding, recovery, and memory. Basically, I propose that location information is stored in VSTM while spatiotemporal information (specifically direction) is stored in LTM. Since location information changes rapidly it would require constant monitoring and updating. Motion and direction on the other hand are stable features, and only requires updating if the target reaches the boundary of the screen in which case the direction of the target is predictably reversed. This may explain why location information is readily available in MOT and perhaps why spatiotemporal information needs to be primed by the recovery screen.

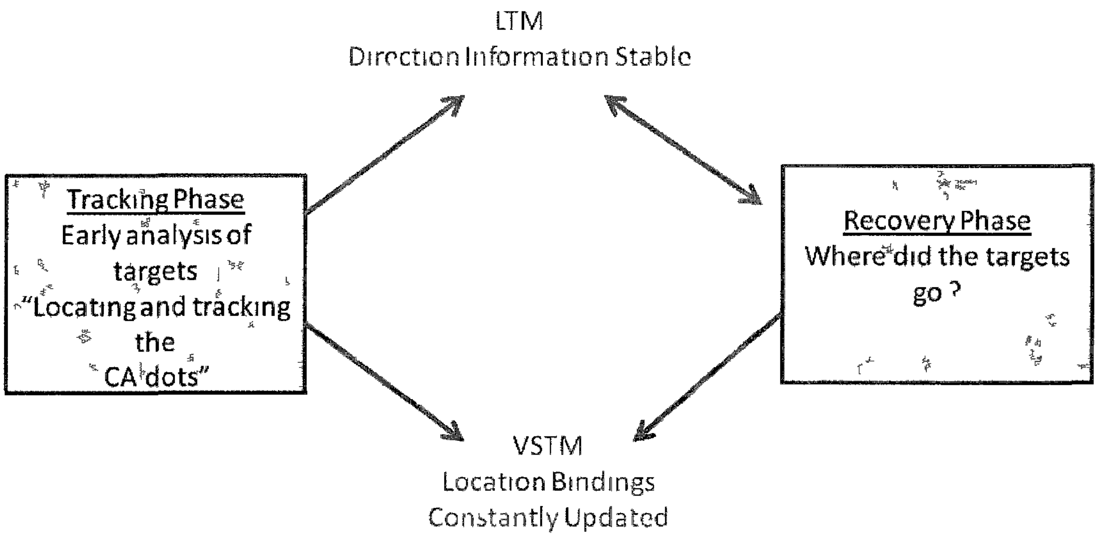

Figure 20 Suggested overview of memory mechanisms involved in MOT.

Limitations

1. One potential limitation of the current research is the blocking of displacement of targets in the first two experiments. Specifically, the use of blocking may have allowed participants to implement encoding strategies specific to the blocked condition. For instance, participants may have made a point to encode location information in situations where targets did not move during the occlusion, whereas they may have made it a point to focus on spatiotemporal information when they knew targets would be displaced.
2. Originally it was expected that motion information would be superior to direction information. It is possible that the inconclusive support for motion encoding as a whole may have been due to the slower than normal object speeds. Support for this comes from the representational momentum research which suggests that representation momentum is only present when targets move at approximately 30 pixels per second, which is approximately twice the speed of the targets in the current paradigm. If representation momentum drives motion encoding it is possible that the reduced speed did not allow for the introduction of representational momentum in tracking. It may also be the case that representational momentum cannot be sustained for 30 seconds.
3. It may also be the case that the inconclusive support for motion encoding could have been due to the lack of speed manipulation in the current experiments to investigate the impact on target recovery.
4. Last, if direction and location information utilizes VSTM and LTM it is possible that individual differences in memory and attention to play a part in MOT.

Future Research

In order to better understand encoded information and memory capacity, future experiments should implement tasks during the occlusions. Specifically, implementing tasks that interfere with STM and the storage of spatiotemporal information would be valuable to further investigating the information that is encoded. For instance, we typically have to make judgements about objects positions in the real-world after having been distracted or interrupted by another task. As such, there is a current lack of understanding about updating and continual tracking of dynamic objects during interruptions, which require individuals to divert their attention from their primary tasks and attend to something altogether different. This is unlike the current dissertation which simply employ's a blank screen that does not demand attentional resources from participants. An interruption, by default, creates a prospective memory task in that observers need to remember to return to their primary task once they have completed the interrupting task (Dismukes, 2008; Dodhia & Dismukes, 2009). It is also predicted that greater similarity between interrupting tasks and primary tasks leads to more intrusion on the primary task. An increase in similarity decreases the likelihood of remembering to return to the primary task or remembering what the primary task was about. As such, interrupting tasks that engage WM should interfere with the recovery of targets.

Another critical aspect of real-world dynamic tracking is decision making or active tracking. Unlike the pre- identified objects in the original MOT paradigms, it is often the case that targets need to be identified based on some criteria. For example, military radar operators may have to identify targets based on threat level or they may need to interact with the target. It is also typical for target sets to change their status and for more active tracking in order to make ongoing decisions about their status. Therefore, future experiments should investigate how higher level cognitive decision making tasks impacts target recovery. Such an experiment would extend theories by Oinonen, Oksama and Hyönä (2009) which suggest that object familiarity has an impact on target recovery. Although their experiments do not require observers to manipulate objects, it is hypothesized that the manipulation of an object would make it more "familiar" to the observer and perhaps changes how the observer encodes information about the target. The practical implication of such research would extend to radar-based domains such as air traffic control which often requires more than passively monitoring targets. Instead of simply having to be concerned with *where is the target* one would also have to be concerned with *what was I doing (goal) and how do I define a target.*

Additionally, it is necessary to investigate the role that speed plays in the recovery of objects. This is especially important given that speed is an inherent part of motion. It is possible that increasing the speed and varying the speed of the targets to a noticeable level would impact the use of motion information. Future research should also manipulate the length of the duration to determine if encoding and recovery are impacted. Perhaps the duration of encoded memory for motion or speed information is not as long as memory for direction. It may also be possible that as trajectory information becomes more unreliable the strategies for encoding change. For instance, direction information may no longer be encoded in situations where direction was not predictable.

Conclusions

The results of this thesis point to the importance of spatiotemporal information and location encoding in MOT. In line with previous MOT theories, the results of this thesis confirm that location information is undoubtedly a salient piece of information in MOT. However, the results go on to suggest that direction and motion information is also encoded in MOT. It is argued that traditional MOT paradigms failed to activate the use of motion and direction cues because of the lack of encoding specify (or at least partial encoding specificity). Stable spatiotemporal information may be stored in LTM and needs to be primed during the recovery phase in order to be used in target recovery to help fill in the gaps. Overall, the theoretical contribution of this thesis is that target recovery is facilitated by an off-line backward extrapolation which uses primed direction information and location to re-find displaced targets.

Such a result has high ecological validity and provides a first glimpse into real-world tracking, as it is often the case that we track targets that continue moving after long occlusions. The proposed target recovery strategy, off-line backward extrapolation, offers a theoretical account of how recovery of targets occurs. Further, it appears as though there is something unique in the facilitation of target recovery when there is motion-to-motion encoding specificity. In the end, these results are a first in pointing to the importance of spatiotemporal information as a whole. Another novel feature of the current experiments is the presence of a long occlusion. This not only adds to the ecological validity, but also provides insight into the storage and memory capacities involved in MOT.

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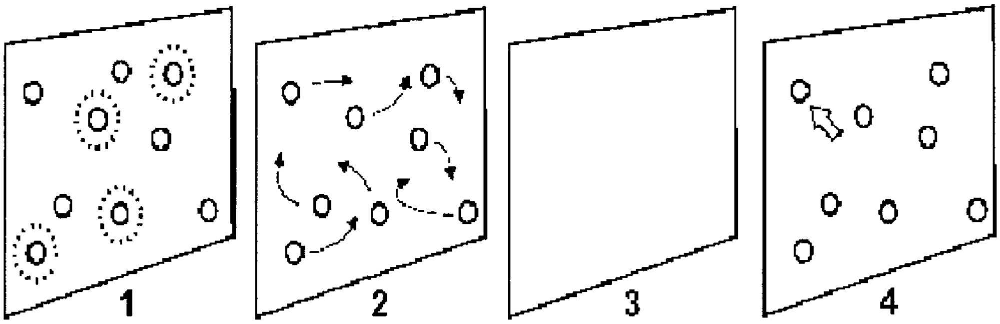
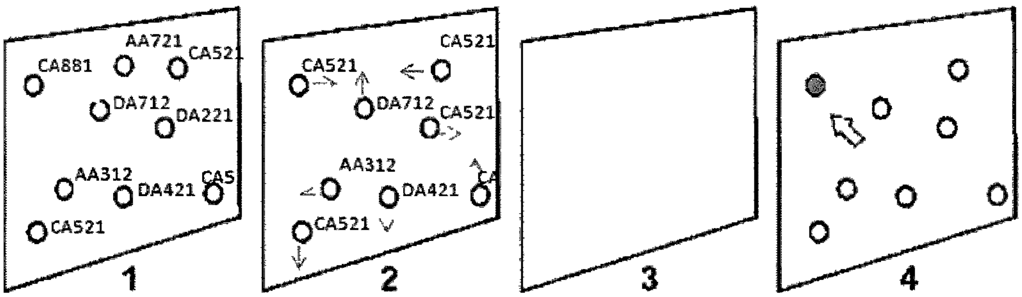
Appendix A. Pilot experiment

Given the limitations of current MOT paradigms, the first main goal of this dissertation was to create a modified version of a multiple object tracking paradigm to allow for a more realistic investigation of multiple object tracking. The proposed paradigm implemented objects which were distinguishable from one another by a five character alphanumeric label. This new paradigm also presented objects moving on predictable trajectories at predictable speeds to better replicate real world parameters. See Figure 21 for an overview of changes made to the paradigm. Prior to beginning the series of proposed experiments this pilot study was completed to determine if the current paradigm still followed the basic MOT principles laid out in the literature. This pilot experiment was also used to determine if the duration of the occlusion was appropriate and did not result in ceiling or floor effects. On average occlusions currently used in MOT research have maximum durations between 1000-3000 msec (Keane & Phylyshyn, 2004; DeLucia & Lidell, 1998). This occlusion length is unrealistic given that on average an interruption in the real-world, such as an office setting, can last for approximately four minutes (Gonzalas & Marks, 2004). Although the occlusions in these experiments will not last for four minutes one main goal of the proposed experiments was to use an occlusion length of 30 seconds. This will allow for an assessment of the type of occluded or interrupted processing that is occurring and it will allow for an investigation into the potential memory capacities involved in MOT. A comparison of the changes between the paradigms implemented by Pylyshyn & Storm (1999) can be seen in Figure 21.



a.) Original MOT Paradigm



b.) Modified MOT Paradigm

Figure 21. Representation of changes to the traditional MOT paradigm (a.) and modified MOT paradigm (b.) to be implemented in the pilot experiment. Modified representation from Pylyshyn & Storm (1999).

Method

Participants

Fourteen undergraduate students (8 females and 6 males) from Carleton University participated in the study. All participants were right handed and had normal or corrected-to-normal vision. Their ages ranged from 18 to 31 (M= 20.36, SD=3.86).

Materials

This experiment employed a modified version of the traditional MOT paradigm. The MOT paradigm used in this experiment was programmed in C++ and presented on a desktop computer. The stimuli consisted of 14 grey dots presented on a black background. Each dot had a five character alphanumeric label located to its upper right. The tracking screen was split into four equal quadrants which were defined by grey lines. The movement of the targets and distracters were completely randomized across all 12 trials. All dots that reached the edge of the screen simply bounced off the side and reversed their direction. Speed of the objects ranged from 4.8 pixels/second to 16.8 pixels/second. Speed was randomized across all objects. See Figure 22 for screenshot of stimuli.

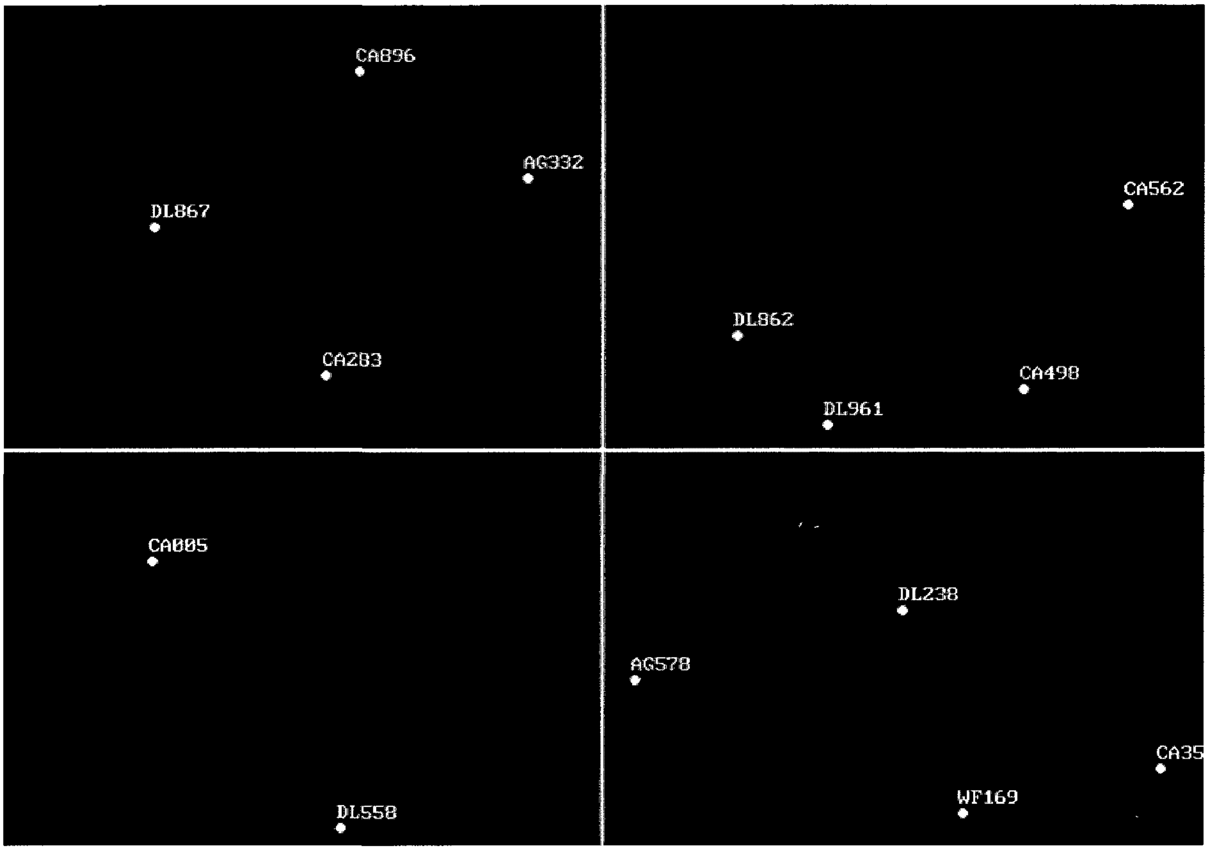


Figure 22. Screenshot of the experimental tracking screen depicting targets and distracters.

Procedure

In accordance with the Carleton University ethics guidelines, prior to beginning the experiment an informed consent form was given to each participant. The informed consent form was explained to the participants, read by the participants, and then signed. A copy of the informed consent form can be found in Appendix B. Following the completion of the informed consent participants were asked to complete a demographics questionnaire. A copy of the demographics questionnaire can be found in Appendix C. At the end of the experiment the goals and hypotheses were explained to the participants and they were given a copy of the debriefing form.

Baseline task.

At the beginning of this experiment, participants familiarized themselves with the task in a five minute training session. During the training session, participants were instructed to track all of the six dots labelled with a "CA". Following the training session participants began the baseline task. In the baseline task the tracking phase lasted for a randomized duration between 25-35 seconds. Randomization of tracking time was used to decrease the predictability of occlusion onset. Immediately after the tracking phase, the screen froze and all alphanumeric labels disappeared. Participants were then instructed to use the mouse to click on the six "CA" targets. Once a dot was clicked it turned red and could not be un-clicked. After the participants clicked on six targets they were instructed to hit enter to move onto the next trial. Each participant completed 12 baseline trials.

Experimental tasks

After the completion of the baseline trials participants proceeded to complete two fully counterbalanced experimental conditions. In both conditions, participants were instructed to track six "CA" targets for a randomized duration (25-35 seconds) amongst eight distracters, just as they did in the baseline task. After the tracking phase ended the tracking screen was occluded by a blank black screen. Participants were instructed to stare straight ahead during the occlusion period. The occlusion period lasted for 30 seconds after which the tracking screen with unlabelled dots reappeared. In the occlusion not-moving condition the dots did not change their location during the occlusion and re-appeared in their pre-occlusion location. In contrast, in the occlusion moving condition, the dots kept on moving at the same speed and direction during the occlusion and reappeared in a new position after the occlusion ended. In each condition participants were instructed to click on the targets as quickly and accurately as possible. See Figure 23 for a screenshot of the recovery phase.

Measures.

Performance accuracy. Accuracy is defined by selecting the correct target. In this experiment that was correctly identifying the objects in the post-screen as a "CA-target". This was recorded as a dichotomous variable correct or incorrect.

Resumption lag. Resumption lag was recorded in seconds and was defined as the time it takes the observer to click on the first target after the occlusion ended.

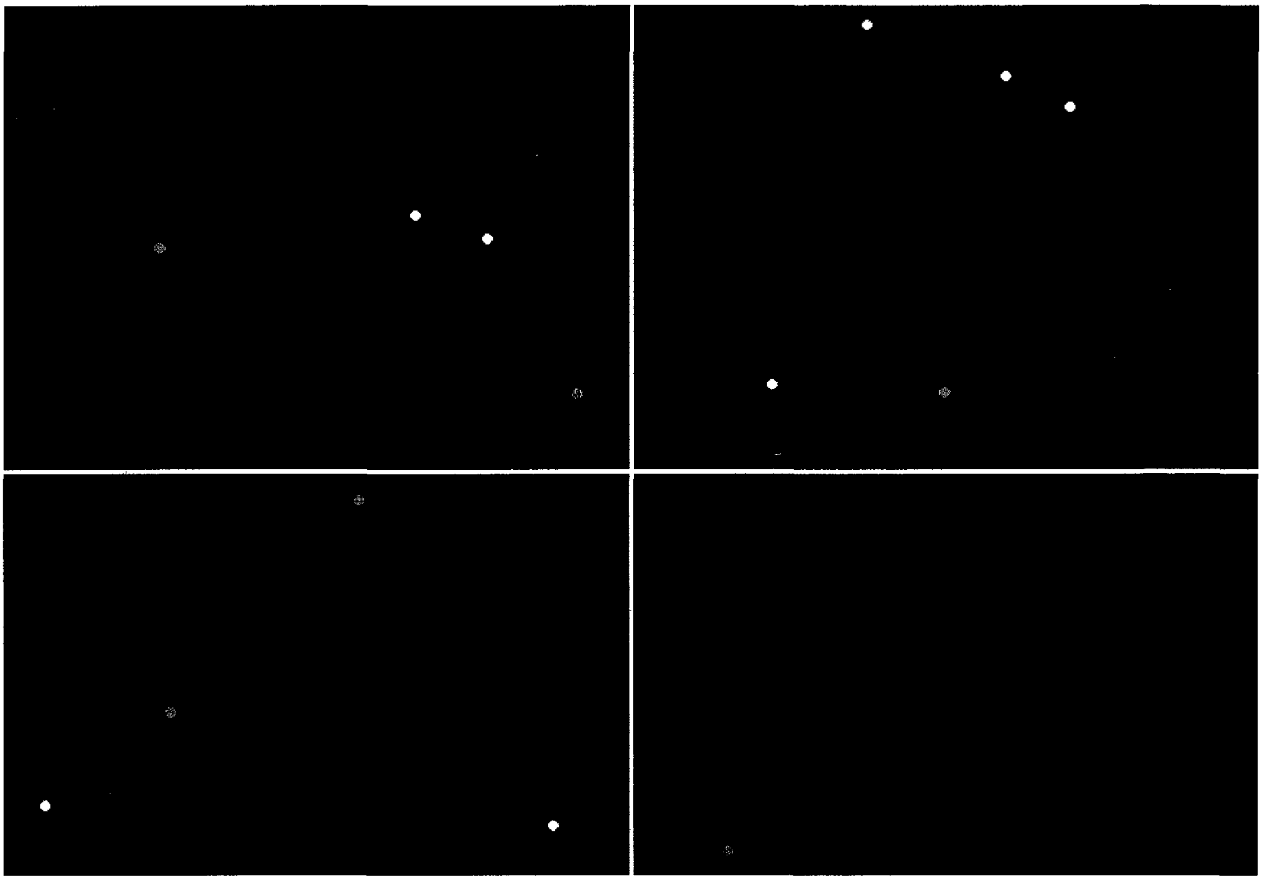


Figure 23. Screenshot of the post-occlusion experimental recovery screen depicting targets and distracters. Red dots indicate objects which have been selected (clicked on) as targets by the participant.

Results

Accuracy.

To assess if there were any learning or fatigue effects throughout, the 12 trials were grouped into three time blocks, each consisting of four trials. Accuracy was analyzed with a 3 (condition: baseline, not-moving, moving) x 3 (time block: beginning, middle, end) repeated measures ANOVA. The results indicated a significant main effect for condition $F\,(1, 26) = 70.61, p<.0001, \eta^{2}_{p} = .85$, but no significant main effect for time block $F\,(1, 26) = 1.34, p=.28$ indicating that there were no practice effects within the experimental conditions. On average, participants had the greatest accuracy on the baseline task $M = 4.96$, $SE =.13$, $CI_{95\%}$ 4.68-5.24, followed by the no movement condition $M= 3.70$, $SE = .20$, $CI_{95\%}$ 3.24-4.09 and finally, the lowest accuracy was found for the movement condition $M= 2.98$, $SE = .09$, $CI_{95\%}$ 2.78- 3.18. See Figure 24 below.

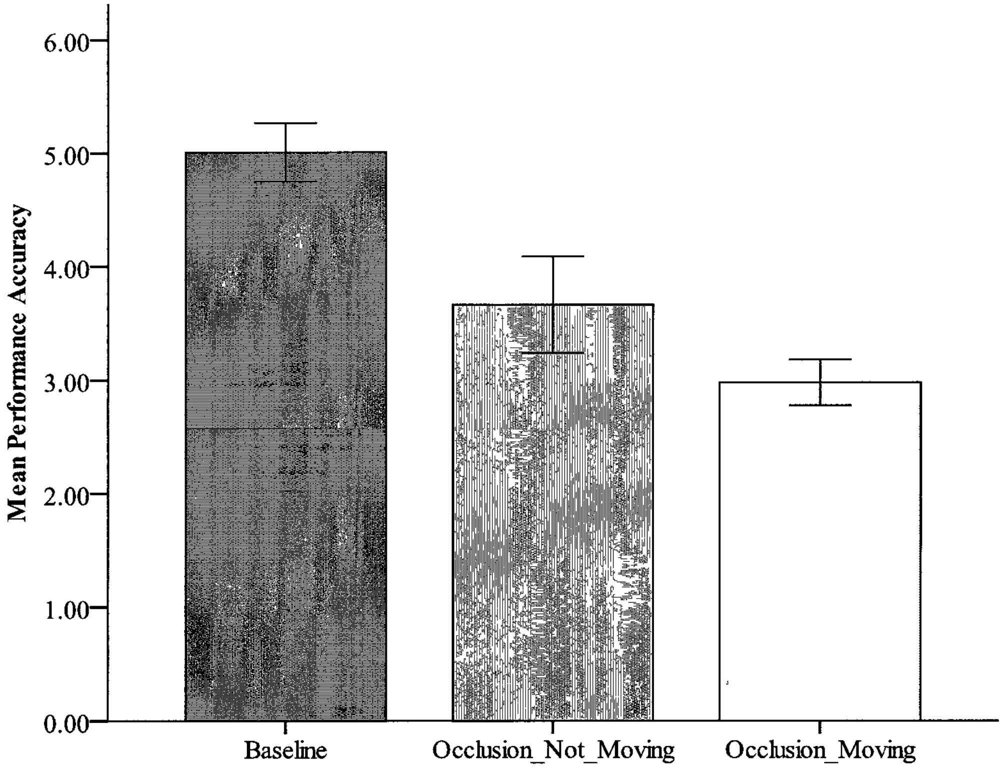


Figure 24. Mean accuracy (number correct) for each condition.

Given that the occlusion period was much longer than is typical in MOT tasks it was important to examine whether or not a reasonable level of performance was able to be maintained across this length of time. The level of accuracy obtained in this experiment is in-line with those reported by both Keane and Pylyshyn (2003) and Alvarez and colleagues (2001). Given that a 30 second occlusion extends beyond the time frame for short-term memory storage without some form of rehearsal or mental visualization these results suggest that spatiotemporal information is stored and used in an active form during the occlusion.

Reaction time.

A 3 (condition: baseline, not-moving, moving) x 3 (time block: beginning, middle, end) repeated measures ANOVA was performed with reaction time as the dependent variable. In order to meet the basic normality assumption of ANOVA a Log (10) transformation was performed on reaction time data. Resumption lag was defined as the time from the end of the occlusion to the first click on a correct target. The results indicated a significant main effect for condition $F(1, 26) = 22.10$, $p<.0001$, $\eta^2_p = .63$ but no significant main effect for time block $F(1, 26) = .85$, $p=.44$. On average, participants had the fastest resumption lag on the baseline task $M = 1.80$ sec, $SE = .10$, $CI_{95\%}$ 1.59-2.02, followed by the not-moving condition $M = 4.14$, $SE = .65$, $CI_{95\%}$ 2.73-5.54 and finally the slowest resumption lag was found for the moving condition $M = 5.97$, $SE=$ 1.95, $CI_{95\%}$ 1.75-10.18. Based on the 95% CI's it appears as though there is a significant difference between baseline and not-moving and baseline and moving but no significant difference between not-moving and moving. The means presented above are based on untransformed reaction time data. See Figure 25 below.

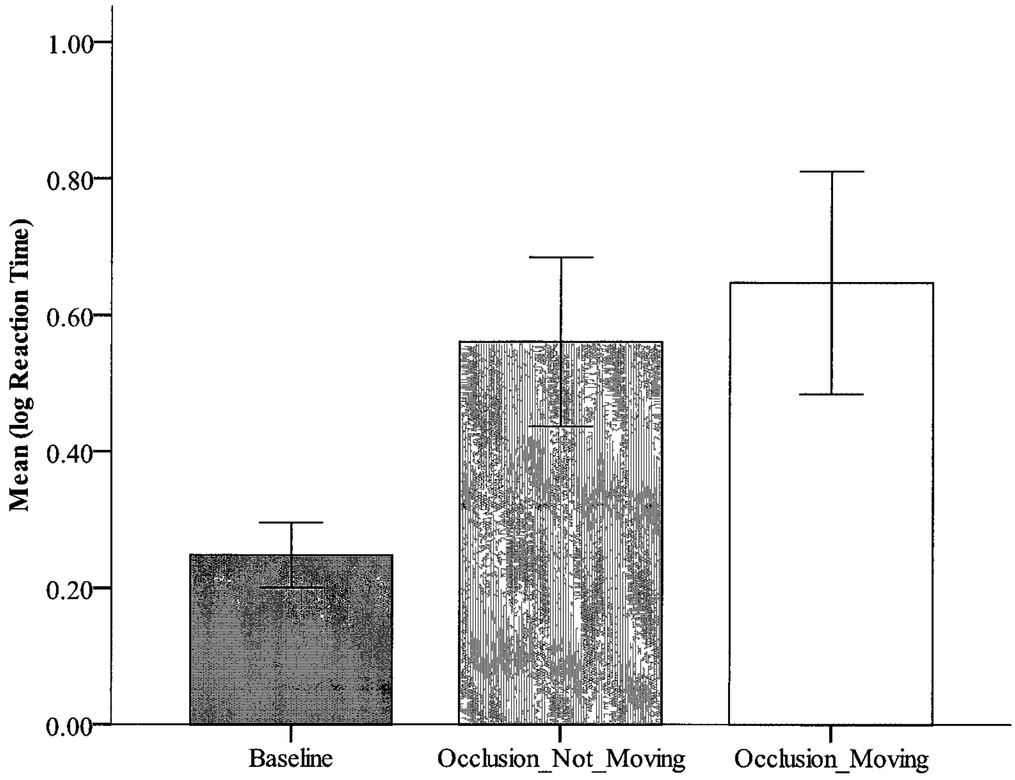


Figure 25. Mean Log (10) transformed reaction time for each condition.

Discussion

Although the occlusion period was much longer than is typical in MOT experiments the results are in-line with those reported by both Keane & Pylyshyn (2003) and Alvarez, Wolfe, Horowitz, and Arsenio (2001). Given that a 30 second occlusion extends beyond the time frame for short-term memory storage without active rehearsal, these results suggest that there is some form of attentional processing of spatiotemporal information. As such, it seems unlikely that location information would survive this length of time without decay as is suggested in location encoding theories. Although at this point it is speculative, it is possible that location information may be rehearsed or spatiotemporal information is maintained in an on-line form during the occlusion making the targets “active” during the occlusion and thus the targets are more easily recovered. It should be noted, however, that the resumption lag provides no indication of how the information is used during the occlusion. If the targets were actively tracked during the moving condition one would have expected that the resumption lag for the moving targets would have been faster than the not-moving condition, simply because the moving condition would match the mental representation of the targets after the occlusion. On the other hand, if location information is the only piece of information that is stored it would seem likely that the not-move condition would have the fastest resumption lag because the mentally stored pre-occlusion location of the targets would match the post-occlusion screen making target location faster than expected in the moving condition. Again, although this is speculative and premature it is possible that spatiotemporal information is stored and used in a retrospective manner as opposed to on-line manner resulting in similar resumption lags in the moving and not moving conditions.

Overall, the length of the occlusion is unique to MOT paradigms and has the propensity to help better identify the type of processing that occurs during occlusions. The above pilot study also confirmed that there were no ceiling or floor effects as a result of the predicable trajectories, slower moving targets, and identifiable targets which are not typical in MOT experiments. Such modifications are necessary to make MOT paradigms more ecologically valid and applicable to more real-world scenarios such as everyday tracking or domain specific tracking such as radar operators. In the end, results replicated those found in earlier studies so it was concluded that the current paradigm was applicable to use in the proposed study. It was important that the current paradigm replicated the results of previous MOT paradigms so that current MOT theories could still apply and be used in the explanation of the results. The intent in modifying the paradigm was to view MOT from a more ecological perspective and test the propensity with which current theories can be extended to include longer more realistic occlusions.

Appendix B. Informed Consent

Study Name: Where did they go? - Recovering dynamic objects after occlusions.

Introduction:

The purpose of this informed consent is to ensure that you understand the reason we are conducting this research and your involvement in the study. The informed consent must provide you with enough information so that you can determine whether or not you wish to participate in this study.

Research Personnel:

The following personnel are involved in this research project and may be contacted at any time:

Principal Investigator:		Faculty Sponsor:
Aren Hunter, PhD Candidate		Dr. Avi Parush
Department of Psychology	or	Department of Psychology
ahunter3@connect.carleton.ca		avi_parush@carleton.ca
613- 520-2600 ext.6628		613-520-2600 ext.6026

If any ethical concerns about this study should arise, please contact Dr. Monique Sénéchal, Department of Psychology 613- 520-2600 ext. 1155. Should you have any other concerns about this study, please contact Dr. Janet Mantler (Chair, Dept of Psychology) 613-520-2600 ext. 4173 psychchair@carleton.ca.

Purpose:

The purpose of this study is to investigate how we are able to recover dynamic objects after being interrupted. Understanding the cognitive processes involved in the recovery of dynamic information is crucial to understanding how we interact with the dynamic environment in which we live. Consider crossing the street in rush hour where it is not uncommon for us to keep track of cyclists and other pedestrians, while monitoring and predicting the trajectory of a nearby car and oncoming traffic. What happens if you were interrupted by a phone call while trying to cross the street? How do you get back up to speed and recover the information that may have changed during the phone call? In essence, these are the questions we are trying to answer in this study.

Task Requirements:

You will be asked to monitor up to six objects that will be moving at various speeds on a computer screen. At random intervals the objects you have been monitoring will be occluded. During this occlusion you will be required to either wait for the occlusion to end or to perform a working memory task until the occlusion ends. After the occlusion has ended the tracking screen with reappear and you will be required to click on the targets you were tracking prior to the occlusion. Your performance accuracy and reaction time will be recorded.

Duration and Locale:

The duration of this study will be l hour and will take place in the spatial cognition lab in Loeb A428. You will be rewarded with 1 % bonus credit in Psyc 1001, 1002, 2001, and 2002 for your participation in this study.

Potential Risk or Discomfort:

There is the possibility for slight discomfort caused by sitting at a computer for an extended period of time. In order to offset the potential for such discomfort you will be given a break approximately every 15 minutes at which time you will be able to move around, get a drink and relax. The discomfort that you may experience would be nothing more than that experienced by simply sitting at a computer.

Confidentiality:

All data will be numerically coded and remain anonymous. The data collected will be coded such that your name will not be associated with it. The data will be used only by the researchers involved in this project.

Right to Withdraw:

You have the right to withdraw from the study at any time without penalty. In the case of a withdrawal from the study you will still be awarded course credit.

I have read the above description of the study and understand the conditions of my participation. I agree to participate in this research project.

Participant Name:________________________________

Participant Signature:_____________________________ Date: ___________________

Witness/Researcher Name:__________________________

Witness/Researcher Signature: _______________________ Date: __________________

This study has been approved by the Carleton University Ethics Committee for Psychological Research.

Appendix C. Demographics Questionnaire

Please answer the following questions. Your name or any other identifiable feature will not be associated with this questionnaire. By providing us with this information we are able to keep track of simple demographics information importnant for this study. If you are uncomfortable answering any of the following questions please leave them blank.

Gender:______________________________________

Age: ____

Degree:______________________________________

Year of study:_________________________________

Are you right or left handed? ____________________

Do you have have normal or corrected to normal vision?	Yes	No
Do you have normal or corrected to normal hearing?	Yes	No
Do you have any known memory impariments?	Yes	No
Do you consider yourself an avid video gamer?	Yes	No

Appendix D. Instructions for Participants

On the screen in front of you, you will see a number of objects with alphanumeric tags located the upper right of the targets. Theses tags represent call-signs in air traffic control environments. So for instance the first two letters represent the airline name. For instance an AC callsign would stand for Air Canada. The number represents the flight number. For instance AC511 is Air Canada flight 511. In this experiment you are responsible for tracking all of the "CA" flights. So you need to keep track of all dots that have a "CA" call-sign. In total there are 14 dots on the screen but there are always 6 "CA" dots and 8 other dots. The dots move on a straight line path from left-to-right, right-to-left, top-to-bottom, and bottom-to-top. In cases where the dots reach the edge of the screen they simply bounce off and reverse their direction. This means there is always a constant number of dots on the screen.

After a period of 25-35 seconds the tracking screen will disappear and be replaced by a black screen. The black screen occludes all of the dots and lasts for a period of 30 seconds. While the black screen is present you need to look straight ahead and focus on the black screen. This means you should not be looking about the room but instead focusing on the screen in front of you. Do not use your fingers to keep track of the dots during this time. During the occlusion the dots will either remain stationary, so they reappear in the same locations prior to the occlusion or they move. When they move they reappear in their displaced locations just as though they continued moving throughout the occlusion.

Once the occlusion is over the screen with the object on it will reappear but the alphanumeric tags will be gone. At this time you are required to click on the dots that you believe are the CA targets you were tracking prior to the occlusion. You need to click on them as quickly but as accurately as possible. Once you have clicked on a target it will turn red. You are unable to unclick a target once you have clicked it so you are stuck with the decisions that you make. Please make sure you are clicking on 6 targets and not more than 6. Once you have clicked your 6 targets please hit enter to proceed to the next trial. If you need a break you may wait as long as you need before hitting the enter key to proceed.

The instructions were explained to the participants a sample scenario was played to illustrate the procedure. If they had any questions or if they wanted to see the illustration for a second time they were told to just ask.

Appendix E. Written Debriefing

Where did they go? - Recovering dynamic objects after occlusions.

What are we trying to learn & why is this important?

The purpose of this study was to investigate how we are able to recover and locate dynamic objects after being interrupted. Understanding the cognitive processes involved in the recovery of dynamic information is crucial to understanding how we interact with the dynamic environment in which we live. Consider crossing the street in rush hour where it is not uncommon for us to simultaneously keep track of cyclists and other pedestrians, while monitoring and predicting the trajectory of a nearby car and oncoming traffic. What happens if you were interrupted by a phone call while trying to cross the street? How do you get back up to speed and recover the information that may have changed during the phone call? In order to answer these questions it is important for us to understand what cognitive processes are involved in the successful completion of these tasks. In the end this study will help advance cognitive psychology and may help in the efficient design of radar screens.

What are the hypotheses and predictions?

In general, occlusions are thought to be detrimental to primary task performance. It is, therefore, hypothesized that tracking performance after an occlusion will be worse than tracking performance before an occlusion. It is also thought that the position of the moving objects may impact our ability to relocate them after occlusions. This is a very interesting prediction but unfortunately the relationship is not entirely predictable. For instance, we do not yet understand if we are better at finding targets if they remain in their pre-occlusion location or if they have predictably moved to their new locations during the occlusion. Your participation in this study will allow us to better answer these questions and provide us with a much greater understanding of how we get back up to speed after occlusions.

Where can I learn more?

Altmann, E. M. & Trafton, J. G. (2002). Memory for goals: An activation-based model. *Cognitive Science, 26*, 39-83.

Altmann, E. M. & Trafton, J. G. (2007). Time course of Recovery from Task Occlusion: Data and a Model. *Psychonomics Bulletin and Review, 14*, 1079-1084.

Pylyshyn, Z. W. (2004). Some puzzling findings in multiple object tracking (MOT): Tracking without keeping track of object identities. *Visual Cognition, 11*, 801 – 822.

Pylyshyn, Z. W. & Storm, R.W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision, 3*, 179 - 197.

What if I have questions later?

If you have general questions about this study such as the purpose or results of the study please feel free to contact:

Aren Hunter or Avi Parush

Department of Psychology

Carleton University

Ottawa ON, K1S 5B6

Social Sciences Research Building

ahunter3@connect.carleton.ca

(613) 520-2600 ext. 6026

If you at anytime felt uncomfortable during the experiment, feel uncomfortable after the completion of this study, or you have any other ethical concerns please contact:

Dr. Monique Sénéchal, Ethics Chair		Dr. Janet Mantler, Dept. Chair
Department of Psychology		Department of Psychology
Carleton University	or	Carleton University
613- 520-2600 ext. 1155		613-520-2600 ext. 4173
monique_senechal@carleton.ca		psychchair@carleton.ca

This study has been approved by the Carleton University Ethics Committee for Psychological Research.