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Sustained attention to objects' motion sharpens position representations: Attention to changing position and attention to motion are distinct

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ABSTRACT

In tasks where people monitor moving objects, such the multiple object tracking task (MOT), observers attempt to keep track of targets as they move amongst distracters. The literature is mixed as to whether observers make use of motion information to facilitate performance. We sought to address this by two means: first by superimposing arrows on objects which varied in their informativeness about motion direction and second by asking observers to attend to motion direction. Using a position monitoring task, we calculated mean error magnitudes as a measure of the precision with which target positions are represented. We also calculated perceptual lags versus extrapolated reports, which are the times at which positions of targets best match position reports. We find that the presence of motion information in the form of superimposed arrows made no difference to position report precision nor perceptual lag. However, when we explicitly instructed observers to attend to motion, we saw facilitatory effects on position reports and in some cases reports that best matched extrapolated rather than lagging positions for small set sizes. The results indicate that attention to changing positions does not automatically recruit attention to motion, showing a dissociation between sustained attention to changing positions and attention to motion.

1. Introduction

Multiple object tracking (MOT) tasks are frequently used to explore visual attention. This type of task requires participants to track a number of indicated targets as they move around a screen amongst distracters. At the end of a trial the participant is typically asked to indicate whether one of the objects appearing on the screen is a target or not. Pylyshyn and Storm (1988) originally proposed that we have an architectural constraint on tracking based on a fixed number of pointers or FINSTs which can be used to track targets. We now know however that the limit on performance is not set by a fixed number of slots (e.g. Alvarez & Franconeri, 2007; Howard & Holcombe, 2008) but rather depends on a host of factors including speed (Holcombe & Chen, 2013) and inter-object spacing (Franconeri, Jonathan, & Scimeca, 2010).

One issue under debate in the literature is whether or not motion information is used in one way or another during attentional tracking and attention to moving targets. In multiple object tracking tasks, motion information might be useful since it may increase the distinctiveness between objects on the basis of their different motion characteristics, as other visual aspects of distinctiveness have been shown to aid tracking (Makovski & Jiang, 2009). In traditional MOT tasks and more generally in attentional tracking of moving objects, it is possible that motion processing may facilitate the mechanism by which we represent the changing positions of objects. Position and motion are encoded in overlapping but non-identical areas of the brain. Primary and secondary visual cortices process spatial information such as position, and motion is also thought to be processed in these areas, as well as higher order areas such as V3 and V5/MT: Zeki et al. (1991) used PET to show that motion perception recruited areas V1/V2 and V5. From this, is it not clear whether position monitoring would automatically recruit the neural systems subserving motion processing, nor whether directing attention to motion would facilitate processing of positions of objects as they move.

How might attention to motion facilitate position monitoring? One possibility is that it may increase activation or sensitivity in position processing areas of cortex. In an fMRI study, Büchel et al. (1998) used a speed change detection task to engage attention to motion, showing that attention to motion increased activation in V3/V5 and the V1/V2 border over and above the activity

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seen for passive motion viewing. In this study, it is of note that attention to motion increased activation in the earlier areas of V1 and V2 and this may reflect a neural substrate of the facilitatory effects of attention to motion on position perception. This conjecture is supported by the fact that in the study by Zeki et al. (1991), expectations about motion appeared to modulate V1 activity even when the stimulus was static: more V1 activity was recorded for static stimuli when participants knew they would be viewing motion on subsequent trials than when they were expecting non-motion (colour) stimuli. If attention to motion facilitates lower-level spatial vision such as position perception, then it could be the case that this comes about by enhancement of cortical responsiveness in primary and secondary visual cortex.

Another way in which motion information may be used by the visual system is to support extrapolatory processes. There are several reasons why a mechanism that predicts near future states of objects may be helpful in MOT and position monitoring more generally. If the visual system could take account of the current trajectories of objects, then it may be able to compensate for neural delay incurred by the processing of visual information. Additionally, because of the demands on attention during tracking, there may be occasions where attention lapses momentarily, when targets and distracters become in danger of being confused, and where attention may switch between targets. In all these cases, it would be beneficial if the tracking mechanism were able to anticipate where targets would be after a brief interval of attention lapse or other failure to update the representation of target positions. Whether or not the tracking mechanism is able to, or routinely does make use of motion information to perform these extrapolatory processes is still unresolved.

Howard and Holcombe (2008) and Howard, Masom, and Holcombe (2011) observed in a position report MOT paradigm that when asked to report the final position of targets, observers tend to report slightly out-of-date positions. In other words, position reports exhibited perceptual lag. In these experiments, observers tracked a varying number of objects under a range of speed, trajectory parameters and tracking region conditions, and observers consistently reported final positions that were more similar to positions occupied in the moments leading up to display offset than they were to the position displayed on the final frame before offset. However, Iordanescu, Grabowecky, and Suzuki (2009) observed the opposite result, that responses were more likely to lie ahead of the final position of objects that in other directions. Atsma, Koning, and van Lier (2012) used a probe detection task to assess the distribution of attention around moving targets and found better performance ahead of the targets' current positions. However, participants are very likely to have adopted a strategy of attending to the region around targets and therefore these data must overstate the diffuse spread of attention around targets. However, the fact that performance was better ahead of the position than behind does lend support to arguments for the role of extrapolation in MOT. The reason for the discrepant results between these studies is not currently clear.

Some studies have used motion trajectories of varying predictiveness in order to assess whether or not motion information may be used to extrapolate near future positions of objects. The results of these studies are also somewhat mixed. Howard et al. (2011) varied predictability of objects' motion in a position report tracking task. In one condition, objects moved with constant speed and direction of motion unless they collided with each other or with the tracking region boundaries, and in another condition, the vertical and horizontal components of their accelerations were constantly and randomly changing. This had no effect on performance or on perceptual lag, suggesting at most a limited role for extrapolatory processes. Similarly, Vul, Frank, Tenenbaum, and Alvarez (2009) varied the inertia of objects' motion during tracking. They found that performance was not affected by this manipulation of predictability. In contrast, Howe and Holcombe (2012) varied the predictability of objects' motion using two or four targets. In the predictable condition, objects travelled in straight lines until they collided with the edges of the display. In the unpredictable condition, they changed direction of motion randomly and with unpredictable frequency. They observed better performance in the predictable than the unpredictable condition, but only for tracking two targets. This suggests that direction of motion information was useful in some way but only for a limited number of targets. The main difference between this study and the previous two that did not report predictability effects is that in this study only direction of motion predictability was manipulated and not speed variability. Speed changes may therefore be less susceptible to extrapolatory processes. Another possibility is that the sudden direction changes may actually have attracted attention as they have been shown to under some circumstances (Howard & Holcombe, 2010). This may be detrimental to performance when changes occur in distracter objects. In any case, the evidence for whether or not trajectory predictability plays a role in performance is as yet unresolved.

Several recent studies have introduced motion to the surface texture of objects in order to investigate the role of motion information in tracking performance. If motion information is used to predict near future trajectories of targets during tracking, then introducing any motion that is not consistent with the direction of travel should disrupt performance. It seems reasonable to suggest that motion information may be used in this way since it could aid in target recovery during brief tracking failures or switching of attention between targets.

An advantage of this method is that this surface motion can be manipulated independently of the motion of the object around the tracking space. St. Clair, Huff, and Seiffert (2010) conducted several experiments using this technique of varying the direction and speed of surface motion relative to the translating motion of objects undergoing MOT. They reported poorer performance when the surface motion moved in the opposite direction to object motion, and to a lesser extent, when surface motion was orthogonal to object motion, than when surface motion was consistent with the actual direction of travel of objects. Interestingly, manipulations of surface motion speed had no consistent effect on performance.

This effect has since been replicated and shown even when different objects within a display possess different surface motion characteristics. Meyerhoff, Papenmeier, and Huff (2013) introduced a condition in which some objects' surface texture moved in the same direction as object motion, and some had texture which moved in the opposite direction to travel. Individual targets with opposite motion were shown to be lost more often than those with consistent surface motion. Thus it appears that whatever processes are affected by surface motion appear to operate on an object based level. Huff and Papenmeier (2013) also report that alternating motion between consistent and opposite motion results in intermediate levels of performance between performance levels seen for simple consistent and opposite motion conditions. Further, the longer the periods of consistent motion compared to opposite motion, the more performance resembled that seen in the consistent condition.

One possibility is that the effects of non-consistent surface motion are due to disruptions of extrapolatory processes. However, another possibility is that surface motion affected position representations and this interpretation is problematic for accounts of tracking that propose facilitative effects of consistent surface motion. De Valois and De Valois (1991) found that surface motion affects where people perceive an object to be, even if the object is not physically moving and not being displaced in position. Hence