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Comparing eye movements during position tracking and identity tracking: No evidence for separate systems

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Abstract There is an ongoing debate as to whether people track multiple moving objects in a serial fashion or with a parallel mechanism. One recent study compared eye movements when observers tracked identical objects (Multiple Object Tracking—MOT task) versus when they tracked the identities of different objects (Multiple Identity Tracking—MIT task). Distinct eye-movement patterns were found and attributed to two separate tracking systems. However, the same results could be caused by differences in the stimuli viewed during tracking. In the present study, object identities in the MIT task were invisible during tracking, so observers performed MOT and MIT tasks with identical stimuli. Observer were able to track either position and identity depending on the task. There was no difference in eye movements between position tracking and identity tracking. This result suggests that, while observers can use different eye-movement strategies in MOT and MIT, it is not necessary.

Keywords Eye movements and visual attention · Attention: object-based

Tracking multiple moving items is a basic skill of daily life. For example, when we drive on a busy highway, we monitor the locations of other vehicles around us to make sure we keep a safe distance. We might also keep track of the identity of vehicles because, for example, we might not want to do anything dramatic if the state police are driving next us. The ability to track the positions of multiple moving objects has been extensively studied (Pylyshyn & Storm, 1988; Scholl, 2009). The standard finding is that observers can track about four moving items among identical distractors. This capacity is not rigidly fixed and can vary with movement speed (Alvarez & Franconeri, 2007) or object spacing (Franconeri, Jonathan, & Scimeca, 2010), and it can be facilitated if each object has a unique feature (Horowitz et al., 2007; Makovski & Jiang, 2009).

Unlike simply tracking the positions of identical objects, tracking the identities of objects with unique features requires that observers constantly update and bind a target's location with its identity. A number of prior studies have investigated the relationship between position tracking and identity tracking. One of the central concerns of that work has been whether position tracking and identity tracking are governed by the same mechanism. Pylyshyn (2004) showed that during tracking, observers had only limited access to the features of tracked targets. Other studies also found that the capacity for tracking identity was consistently lower that the capacity of tracking locations (Horowitz et al., 2007; Oksama & Hyönä, 2004). This lower capacity could be explained by a model with two independent processes: one that would handle position tracking while the other would be responsible for binding identity and location (Horowitz et al., 2007). However, a more recent study found that observers could trade off performance between position tracking and identity tracking, implying that they involved a common resource and were unlikely to be carried out by two independent systems (Cohen, Pinto, Howe, & Horowitz, 2011).

Most recently, Oksama and Hyönä (2016) compared patterns of eye movements in multiple object tracking (MOT) and multiple identity tracking (MIT) tasks in order to investigate whether position and identity tracking are controlled by

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two different mechanisms. They found distinct eye-movements pattern for MOT and MIT. More importantly, the number of fixations, the number of target visits, and the number of updated targets all increased with the tracking set size in MIT but not in MOT. Oksama and Hyönä (2016) argue that these differences in eye-movement measures are evidence of two separate systems involved: A parallel tracking mechanism was used in position tracking, and a serial tracking system was used in identity tracking. In their experiments, however, the stimuli differed between tracking tasks. Thus, it is possible that the eye-tracking differences are caused by the stimulus differences rather than by different underlying MOT and MIT processes. For instance, in their Experiment 3, there were four identical line-drawing stimuli in the MOT task and four distinct line drawings in the MIT task. Thus, since the targets were always distinguishable from distractors during identity tracking but not during position tracking, it is hard to tell whether the distinct eye-movement patterns were the result of the use of different stimuli or of different tracking mechanisms.

The goal of the current study is to test whether the patterns of eye movement for MOT and MIT would still be distinct if the stimuli were identical during tracking. In many previous identity-tracking studies, the targets' identities were continuously visible throughout the tracking and were only hidden in the end (e.g., Horowitz et al., 2007; Oksama & Hyönä, 2004). This might produce a distinct pattern of eye movement because if observers were to lose track of an item, then they could search for the remembered identity and thus recover the target location. However, the same recovery process would not be possible in a standard MOT task where targets are indistinguishable from distractors during tracking. Therefore, if the eye-movement patterns remain different between MOT and MIT when the identities are hidden during tracking, this would be a strong indicator that there are two separate systems involved in position tracking and identity tracking. Alternatively, if eye movements are similar between two tracking tasks when the identity is invisible, then it would suggest that the differences, found in previous studies, might be a side-effect of the visibility of the identities rather than being clear evidence for two mechanisms.

Method

Participants

Twelve participants (nine female) were recruited from the Brigham and Women's Hospital Visual Attention Lab volunteer pool. All had normal or corrected-to-normal vision and passed the Ishihara color screen. Participants gave informed consent approved by the Brigham and Women's Hospital Institutional Review Board and were paid $10/hour. Participants ranged in age from 18 to 37 years. The number of participants was based on the number that has proven adequate in previous experiments of this sort. A post hoc analysis indicates that 12 observers would be adequate to detect a 0.4 main effect of tracking set size (alpha = 0.05, power = 0.8). Since this study concerns the absence of a difference between conditions, we will report on Bayesian statistical tests of the likelihood of the null result.

Apparatus

Eye movements were recorded by a desktop mounted Eyelink 1000 system (SR Research Ltd, Ontario, Canada) with sample rate of 1000 Hz. Stimuli were presented on a 19-in. Mitsubishi Diamond Pro 991 TXM CRT monitor, with a screen resolution of 1024 × 768, and a refresh rate of 75 Hz. The visual display subtended 37° of visual angle horizontally and 30° vertically at a viewing distance of 65 cm, and a chin rest was used to stabilized the head. Viewing was binocular, but only the right eye was tracked. The experiments were written in MATLAB 8.3 with Psychtoolbox Version 3.0.12 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997).

Stimuli

The stimuli consisted of 10 unique cartoon animals (see Fig. 1). On each trial, all items were randomly selected from a set of 25 different cartoon animals. Each item subtended about 3° × 3° of visual angle. The background was white. Three to five out of the 10 total animals were the targets and were marked by red outlines during the memory phase. During the tracking phase, all items would be replaced by identical dark-gray circles with black outlines then start to move with a velocity 6°/s within an imaginary 25° × 25° window. All items moved in straight lines, except when they bounced off each other or when they hit the boundaries of the imaginary window.

Procedure

The multiple object tracking and the multiple identity tracking were conducted in separate blocks, and the order of the blocks was counterbalanced. The multiple object tracking experiment consisted of three blocks of 30 trials, each with a different target set size of three, four, or five out of total 10 animals. Observers were asked to track the target animals among distractors. At the start of the trial, all animals were stationary, and observers could take as much time as desired to memorize the targets' locations. Observers would press the space key to start tracking when they were ready. After the key was pressed, all open outlined circles would gradually close and turn to identical gray circles. Once all circles were closed, all items would start to move with velocity 6°/sec. The movement

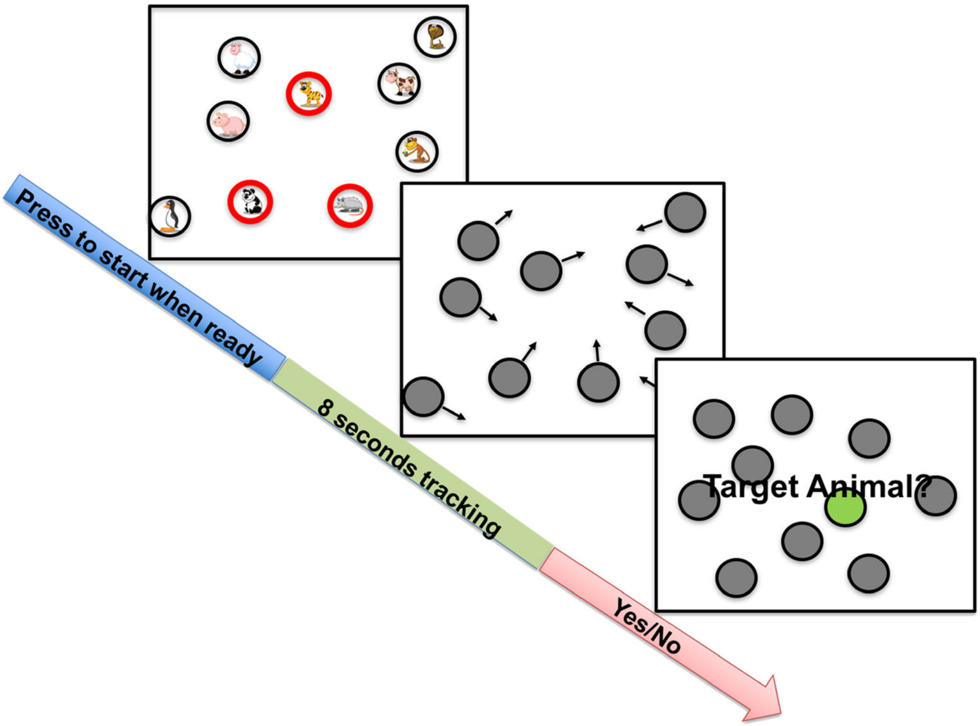

Fig. 1 Stimuli and procedure used in the MOT task. During initial memorization phase, all 10 items were stationary and their identities were visible. Observers were asked to memorize targets' location. During the tracking phase, all 10 open circles would gradually close, becoming gray circles that moved for 8 seconds. During the testing phase, one of 10 circles would be probed, and observers had to answer whether the circle was one of the targets. (Color figure online)

would last for 8 seconds. When the movement stopped, one of the circles was probed, and observers had to respond by key press to indicate whether the probed circle was a target. Accuracy feedback was given after the response was made.

In the identity-tracking task, the procedure was the same as in position tracking, except observers were asked to memorize and then track the identities of target animals (see Fig. 2). At the end of tracking, one of the target items would be indicated by a probe. Next, an animal would be presented at the center of the screen. Observers had to respond by key press whether this animal, shown at the center, was the same as the animal hidden at the probed location. Note that unlike most identity-tracking tasks in which all stimuli remain visible throughout the tracking period, our identity-tracking task allowed observers to view target identities only during the initial memorization phase, not during tracking. Thus, during the tracking phase, stimuli were completely identical in the MOT and MIT tasks.

Data analysis

We compared the eye movements between the MOT and MIT tasks in order to investigate whether the different eye-movement patterns, found by Oksama and Hyönä (2016), were due to distinct systems for encoding identity and location or were due to stimulus differences during tracking. Eye-movement data were parsed into fixations and saccades by the Eyelink parser. Next, all fixations were assigned to one of four areas of interest: targets, distractors, the centroid of all targets, and everywhere else ("elsewhere"). The diameters of the areas of interest for each target and distractor and for the centroid were set to 4 degrees. The centroid was defined as the center of gravity of the targets, which was calculated by averaging the position of all targets. As targets and distractors kept changing their locations during fixations, a target may be fixated initially but no longer be fixated at the end of fixation. Thus, we used a similar algorithm to assign fixations as used in the previous study (Oksama & Hyönä, 2016). Since the items were continuously moving, a fixation that started in one area of interest (e.g., on a tracked target) might end up in another area (e.g., "elsewhere"). For analysis purposes, each fixation was assigned to only one area of interest. That was the area where it was located for more than 50% of its duration. Fixations shorter than 80 ms were excluded from the analysis (our data are available at https://osf.io/846ry/).

Results

The average tracking performances were 96%, 89%, and 86% in the MOT task, and 93%, 85%, and 79% in the MIT task for Set Size 3, 4, and 5, respectively.

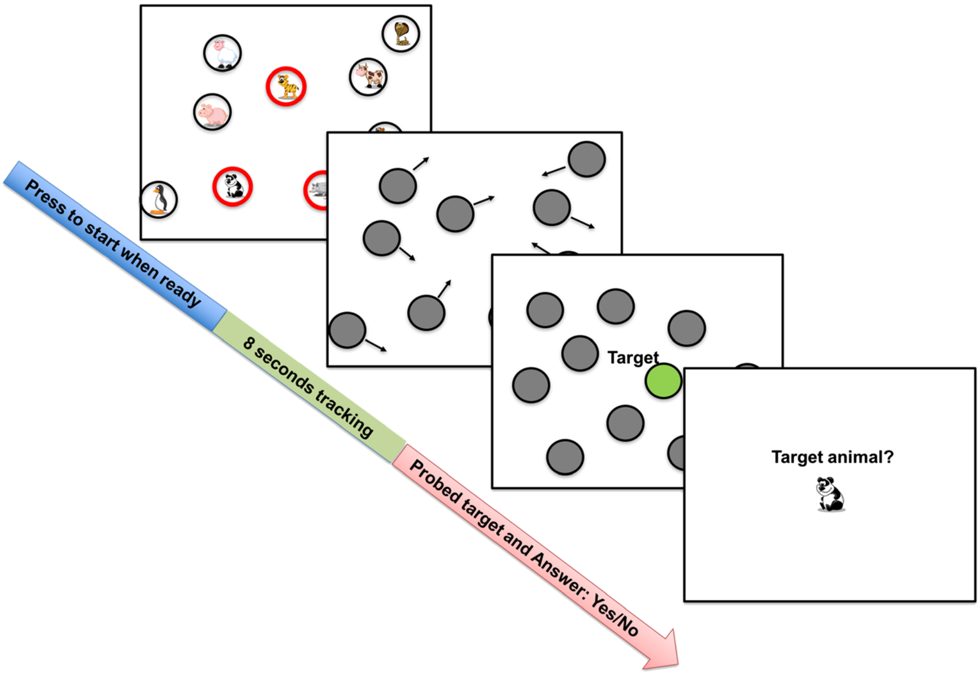

Fig. 2 Stimuli and procedure used in MIT task. During initial memorization phase, all 10 items were stationary, and their identities were visible. Observers were asked to memorize targets' identities. During tracking phase, all 10 open circles would gradually close, becoming gray circles that moved for 8 seconds. During testing phase, one of target circles would be probed, then one of the target animals was presented. Observers were asked whether the animal shown was the animal located at the probed circle. (Color figure online)

Number of fixations

A serial tracking model would predict that the number of fixation should increase with tracking set size as observers had to shift attention from one target to another. As shown in Fig. 3, the number of fixations made during MOT did not increase with tracking set size. More importantly, the number of fixations during MIT did not increase with tracking set size, either. A two-way repeated-measures ANOVA shows that there was no effect on set size or on task type (see Table 1). No interaction was found between set size and task type, $F(2, 22) = 0.64$, $p = .54$, $\eta_p^2 = 0.06$. This MIT result differs from the Oksama and Hyönä (2016) study, in which the frequency of fixation in MIT always increased with target set size.

Number of target visits

The previous study found that the number of fixations on target objects increased with set size in MIT but not in MOT. Figure 4 shows that, as with the total number of fixations, the number of target fixations did not increase as a function of set size for either MOT or MIT when the objects' identities were invisible. ANOVA and Bayes factors analyses (presented below) show that there was no effect of set size or of task type (see Table 1). No interaction was found between set size and task type, $F(2, 22) = 0.56$, $p = .58$, $\eta_p^2 = 0.05$).

Number of updated targets

The previous study examined the seriality of tracking by measuring how many targets were fixated at least once during tracking. They found that the number of updated targets increased with tracking set size only in MIT but not in MOT, which suggests that observers tracked targets serially to update target identities during MIT. To test whether the same strategy was used even when identities were hidden during tracking, we compared the numbers of updated targets between two tasks. Each updated target was fixated at least once. As shown in Fig. 5, the number of updated targets increased

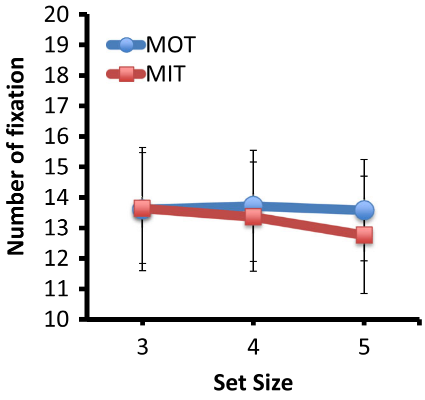

Fig. 3 Number of fixations made as a function of target set size for MOT (blue) and MIT (red). Error bars are ±1 *SEM*. (Color figure online)

Table 1 Repeated-measures ANOVA and Bayesian repeated-measures ANOVA. The Bayes factor **BF01** shows the likelihood of data under the null than under the alternative

Measures	*F* test on task type	η_p^2	BF01 on task type	*F* test on set size	η_p^2	BF01 on set size
# Fixations	$F(1, 11) = 0.31, p = .59$	0.03	3.08	$F(2, 22) = 0.26, p = .78$	0.02	6.84
# Target visits	$F(1, 11) = 1.63, p = .23$	0.13	0.83	$F(2, 22) = 1.13, p = .34$	0.09	4.90
# Updated targets	$F(1, 11) = 0.60, p = .46$	0.05	2.81	$F(2, 22) = 8.78, p = .002$	0.44	0.02
Fixation duration	$F(1, 11) = 0.07, p = .79$	0.01	3.76	$F(2, 22) = 0.79, p = .47$	0.07	5.48
Pupil size	$F(1, 11) = 0.61, p = .45$	0.05	1.81	$F(2, 22) = 2.78, p = .08$	0.2	2.38

slightly with set size. Nevertheless, this increase was rather modest and was seen in both the MOT and MIT tasks. No difference in the number of updated target was found between two tasks. There was no interaction between task type and tracking set size, $F(2, 22) = 0.14$, $p = 0.87$, $\eta_p^2 = 0.01$. This result does not support the hypothesis that there is a strategy of serially updating target identities in MIT, at least not when the identities were invisible during tracking.

Fixation duration

Oksama and Hyönä (2016) found that the average fixation duration in MIT was smaller than in MOT and decreased with set size. The shorter duration was in agreement with the assumption of serial tracking. That is, if observers serially fixated the targets that were just visited before, the time needed to update the familiar positions and identities would be shorter, and this would result in an overall shorter duration. In the present study, when the identity was hidden during MIT, the fixation duration in MIT showed no difference from the duration in MOT. In addition, the average fixation duration did not vary with tracking set size in both tasks (see Fig. 6). No interaction was found between set size and task type, $F(2, 22) = 0.21$, $p = .81$, $\eta_p^2 = 0.02$. Interestingly, the fixation durations were quite long and were similar to those in previous MOT experiments (about 600 ms).

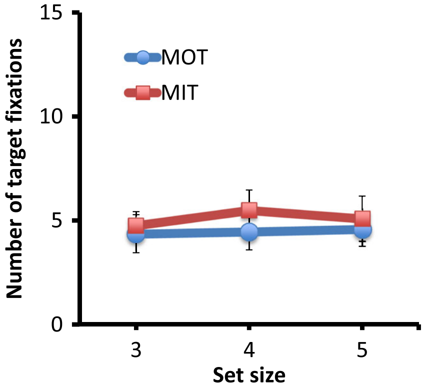

Fig. 4 Number of target fixations as a function of target set size for MOT (blue) and MIT (red). Error bars are ±1 *SEM*. (Color figure online)

Pupil size

To examine the possible difference of attentional load between MOT and MIT, we measured the pupil size during tracking since increased load is associated with larger pupil size. Oksama and Hyönä (2016) found that pupil size increased with tracking set size for both MOT and MIT, and the increase in MIT was higher and more robust than in MOT. In our study, we only found a marginal increase in pupil size with set size in MOT and MIT ($p = .08$; see Table 1 and Fig. 7). Importantly, there was no difference in pupil size between MOT and MIT, suggesting no significant difference in attentional load between the two tasks. No interaction was found between set size and task type, $F(2, 22) = 1.99$, $p = 0.16$, $\eta_p^2 = 0.15$. It could be that the larger, more reliable increase in pupil size in MIT in the Oksama and Hyönä (2016) study was related to the updating of item identity.

Average percentage of fixations landed on different areas of interest

Figure 8 shows that observers made more fixations on targets or a centroid of the target positions than on distractors. Of more interest, there is only one small difference between the

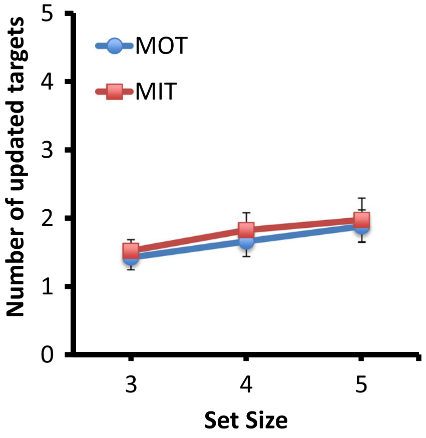

Fig. 5 Number of updated targets as a function of target set size for MOT and MIT. Error bars are ±1 *SEM*. (Color figure online)

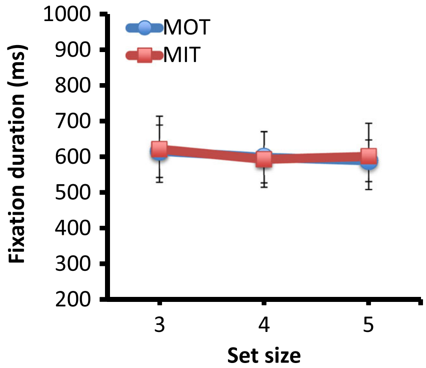

Fig. 6 Fixation duration as a function of target set size for MOT and MIT. Error bars are ±1 *SEM*. (Color figure online)

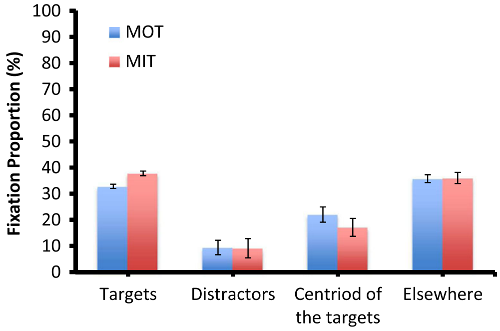

Fig. 8 Percentage of fixations landed on the targets, distractors, centriod of the targets, or elsewhere on the screen for both MOT (blue) and MIT (red). Error bars are ±1 *SEM*. (Color figure online)

pattern of fixations in MOT and MIT conditions. The number of fixations on tracked items goes up in the MIT condition, a paired *t* test shows that $t(11) = 3.01$, $p = .012$, Cohen's $d = 0.87$, while the number of fixations on the centroid of those targets goes down, $t(11) = 3.19$, $p = .009$, Cohen's $d = 0.92$. Fixations on distractors, $t(11) = 0.50$, $p = .63$, Cohen's $d = 0.14$, and elsewhere, $t(11) = 0.15$, $p = .88$, Cohen's $d = 0.04$, remain unchanged.

Time spent on encoding the targets

The abovementioned analyses show there was only a slight change in the distribution of eye movements between position tracking and identity tracking. To better understand where strategies differed between the MOT and MIT tasks, we analyzed the time observers used to encode the target information during the memorization phase. As expected, Fig. 9 shows that the times needed to encode the target information increased with target set size, $F(2, 22) = 23.66$, $p < .001$, $\eta_p^2 = 0.68$, and the time was much longer in MIT than in MOT, $F(1, 11) = 34.51$, $p < .001$, $\eta_p^2 = 0.76$. It is noteworthy that, in the MIT task, the time needed to encode the targets appears to increase nonlinearly with target set size. Observers took 2.7 seconds longer when the target set sizes increased from three to four. But when the target set size increased from four to five, observers took 5.6 seconds longer. This additional increase may reflect limits in working memory capacity. Whatever the cause, once memorization was accomplished and the tracking period began, no differences were seen between MOT and MIT in any eye-movement measures.

Bayes factor analyses of the equivalence of MOT and MIT

In the data, presented above, there is a lack of evidence for a difference between MOT and MIT eye-movement measures when item identities are hidden during MIT tracking. Lack of evidence for a difference is not the same as positive evidence that the two conditions produce the same results. To assess this null hypothesis of similarity between MOT and MIT measures, we conducted a Bayes factor analysis (Bayesian repeated-measures ANOVA). The Bayes factors for the various eye-movement measures were calculated using JASP (JASP Team, 2017), a new statistical package that implements the default Jeffreys–Zellner–Siow priors.

As shown in Table 1, there is some evidence supporting the null hypothesis that MOT and MIT produce the same results. That being said, the evidence is far from overwhelming. Using 3.0 as the boundary between "weak" and "positive" support for the null hypothesis, the null hypothesis is supported in a

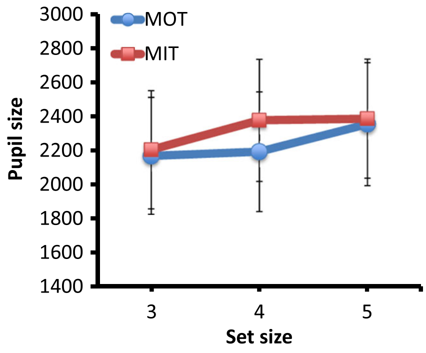

Fig. 7 Pupil size as a function of target set size for MOT and MIT. Error bars are ±1 *SEM*. (Color figure online)

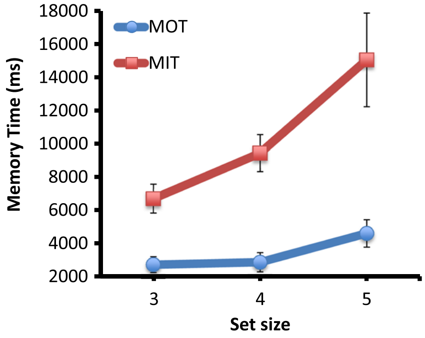

Fig. 9 Time spent during memory phase as a function of target set size for MOT (blue) and MIT (red). Error bars are ±1 *SEM*. (Color figure online)

"positive" manner for number of fixations and fixation duration. Weak evidence is found for the number of updated targets and pupil size. Strong evidence for the equivalence of MOT and MIT measures would require a much larger study, but that is not the goal of this work. Here, we simply wish to know if the large and interesting differences between MOT and MIT remain when identity is not available during tracking. These data suggest that those difference are not seen under the conditions of the present experiments.

Discussion

Eye movements have been used as a measure of the allocation of visual attention because focal attention almost invariably accompanies an eye movement (Deubel & Schneider, 1996; Kowler, Anderson, Dosher, & Blaser, 1995). Many motion-tracking experiments have examined the patterns of eye movements in an effort to understand the underlying tracking strategy. For instance, Zelinsky and Neider (2008) tested how the viewing strategy changes with different tracking set sizes during an MOT task. They found that people tend to use a strategy of looking at the centriod when monitoring a smaller set size but preferred to look at each target when the set size became larger. Similar results were also seen in Fehd and Seiffert (2008, 2010). The study of Oksama and Hyönä (2016) is the first attempt to use eye movements to dissociate the processes between position tracking (MOT) and identity tracking (MIT). Our results suggest that the distinct eye-movement patterns may be related to differences in the stimuli in their two tasks, as target identities were visible during tracking in the MIT task but not during the MOT task. Our results show that when target identity was hidden during identity tracking, no difference in eye-movement measures was found between MOT and MIT, though our observers may have fixated on specific targets a little more than on the centroid of those targets. Perhaps observers fixated on targets when they were attempting to boost their memory for the identity of targets in the MIT task—something that they did not need to do in the MOT task.

More importantly, our results show that both position tracking and identity tracking seem to be the product of the same mechanisms, at least when the items are identical during tracking. The previous study argued that position tracking is achieved by a parallel tracking mechanism while identity tracking is achieved by a serial tracking system, which switches attention from one target to another and leads an increasing eye-movement measure with set size (number of fixations, number of target visits, and number of updated targets). Though we found a small increase in the number of updated targets as a function of set size, the increase was too small to support the serial tracking account, and it occurred in both MOT and MIT. In general, no differences were found between the MIT and MOT tasks. Overall, the current results suggest that when target identity was invisible during tracking, most eye-movement measures were invariant across set sizes (see Table 1). This suggests no serial processing was involved in the identity tracking.

Of course, the finding of no difference between MOT and MIT eye-movement patterns is not the same as proving the null hypothesis that MOT and MIT patterns are identical. Results of Bayes factor analyses, as shown in Table 1, lean toward supporting a "real" lack of difference between the MOT and MIT. The BF01 values are not strikingly large. True evidence that the two conditions were identical would require a more extensive study. However, that is not the main purpose of this experiment. Here, we show that the striking differences between MOT and MIT in earlier work are not seen when items are identical during tracking in the MIT case. It is clear that such differences were not present in the results of the current experiments, though it remains possible that some differences would be measured with a much larger study.

It should be noted that our results do not show that the Oksama and Hyönä (2016) results are "wrong." It is entirely possible that different processes were used in their MIT task because identities were visible during the tracking period. If the items are visible and you lose track of an item whose identity you remember, you could search for it and recover it. This, of course, is not possible for the items that have been made identical during tracking, as they are in our experiment. Indeed, one might regard the Oksama and Hyönä (2016) situation as more "natural" since, under most circumstances, items typically do not lose their identities when they begin to move. While a different process may have been useful to Oksama and Hyönä's observers, the central message in our results is that the use of such a serial tracking process is not necessary in MIT since it is still possible to keep track of identities when those identities are hidden during tracking.

Finally, the very similar eye-movement patterns produced by MIT and MOT in our experiments do not resolve the controversy between the proposals of common or separate systems for position and identity tracking. The absence of a difference may simply demonstrate that the two separate systems do not have separate effects on eye movements. It does not mean that separate systems cannot exist. The patterns of eye movements in the current study may be more strongly driven by other factors, such as object collision (Landry, Sheridan, & Yufik, 2001) or motion extrapolation (Makin & Poliakoff, 2011). The specific choices about the rules governing motion may change tracking strategy. For example, each object in our experiments moved in a straight line with a constant speed, and they would collide with and bounce off of other objects or the walls. This makes the movement more predictable and simplifies the tracking. Given that set of rules, observers might choose to give fewer fixations and/or less attention to an isolated target in favor of focusing on another target that was approaching the other nontargets. The item entering a crowd is more likely to get lost and thus requires more attention. The isolated item can be retrieved from memory because its next position is predictable. Such online demands, based on interactions between stimuli, may affect eye movements more than any other high-level signal, such as position updating or the binding of position and identity. In a different study, Lisi and Cavanagh (2015) found an analogous result in which saccadic eye movements tend to respond to the immediate visual input but not to the accumulated signals used in perceiving the path of a moving target. This suggests that eye movements may be somewhat dissociable from perceptual processing (Kuhn & Rensink, 2016; Spering & Carrasco, 2015).

In summary, studying eye movements is an informative tool for understanding how focal attention is allocated at any given moment during object tracking and which tracking strategy is used (serial vs. parallel tracking). Nevertheless, the current study shows no evidence from eye movements for separate processes for position tracking and identity tracking.

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