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Visually guided computer-mouse clicking interferes with multiple-object tracking (MOT)

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ABSTRACT

Many everyday tasks require coordinated action towards specific items moving amongst others (e.g. touching, pointing). Pylyshyn (2001) proposed that multiple-object tracking (MOT), the ability to monitor positions of specific target items as they move amongst others, is an integral part of coordinated action towards targets. In support of this, Terry and Trick (2021) found that when participants were required to touch any moving item that changed colour (visually guided touch) it not only interfered with MOT – but it interfered differentially, with less interference for touching items that changed colour if they were also targets in MOT. However, direct touch may represent a special case. In this study, we attempted to replicate the finding using a different coordinated action: computer-mouse clicks. Participants tracked 2–3 targets in MOT while clicking any item that changed colour. Mouse-clicking also interfered differentially with MOT, which suggests a common mechanism may underlie these processes.

1. Introduction

Many daily tasks require performing coordinated actions toward moving items (e.g., touching them, pointing at them). Multiple-object tracking (MOT) is the name given to the perceptual ability that allows us to keep track of the positions of a small number of selected items (targets) as they move amongst others (distractors). Pylyshyn (2001) proposed that the operations necessary for MOT are integral to performing coordinated actions such as touching, pointing, or making eye movements towards selected target items amongst others in dynamic environments. To explore this idea, Terry and Trick (2021) performed a series of experiments where participants had to carry out two independent tasks simultaneously. The first task was a standard MOT task where 1–4 items amongst 10 were designated as targets. After this all items became identical and began to move. Later the participant had to report the items that were targets. The second task was visually guided (exogenously directed) touch, which involved touching *any* item that changed colour during the period of item movement of the MOT task. These experiments provided preliminary evidence that visually guided touch interferes with MOT, but they showed it interferes differentially. It was far more detrimental to touch items that changed colour when those items turned out to be distractors rather than targets in MOT (cf., Thornton and Horowitz, 2015). The goal of the present study was to determine whether this effect would generalize to coordinated actions that do not involve direct touch by the fingers.

In this study we had participants tracking selected targets in MOT while at the same time using a computer-mouse to click any moving item that changed colour. There are a variety of reasons that it is important to extend the research in this way. First, when participants touch items on screen, they may cover up other items with their fingers or hands. Although research suggests that the occasional occlusion of individual targets has a minimal impact on MOT (e.g., Scholl and Pylyshyn, 1999), it is possible that having the hands on the screen for periods of time may amplify this effect. It is especially important to disconnect the positioning of the hands from the positions of items on the screen given research that suggests that the positioning of the hands may in itself have complex effects on attention (e.g., Bush and Vecera, 2014; Dosso and Kingstone, 2018).

Second, although individuals generally tend to fixate on a central point between the targets in MOT (Fehd and Seiffert, 2008), it is possible that the interference observed in Terry and Trick (2021) might stem from eye movements made while directing the fingers towards items. In particular, when participants touch items with their fingers during tracking, they may look at the effector (the index finger of their dominant hand) for those actions. However, when participants use a computer mouse to click on items, the effector for the action is the hand using the computer mouse. Thus, it is less likely that participants look at their hands while using a mouse. It would be more useful to look at the cursor, the projection of the position of the mouse on the screen. In this study, we investigate where the results of Terry and Trick (2021) replicate when using a different motor response.

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The comparison between mouse-clicks and visually guided touch is interesting because touch is a more natural behaviour than computer-mouse use. We evolved to touch items with our fingers and learned to do this early in life. Studies that compare direct finger-touch to mouse-clicks generally find finger-touch is faster (e.g. Cockburn et al., 2012; Moher and Song, 2019; Watson et al., 2013) though there is controversy about accuracy. Sasangohar et al., 2009 found that though finger-touch was faster than mouse-clicks, it was less accurate (error rates: 9.8% vs. 2.1% respectively). In contrast, Watson et al. (2013) reported finger-touch was both faster and more accurate than mouse-clicks. Unfortunately, the literature on mouse use has focused primarily on response to static rather than moving items. Thus, by investigating response to moving items, the present study extends the literature on mouse use as well. If the differential interference observed between MOT and visually guided touch does not replicate when individuals click with a mouse, this would suggest that different cognitive mechanisms are used for finger-touch and mouse-clicks.

In the present study participants performed a MOT task where they tracked 2–3 items amongst 10. Single-task performance (MOT alone) was compared to dual-task (MOT + clicking the mouse on any item that changed colour). Because there was a danger that colour change *per se* might produce differences in performance depending on whether the changing items were targets or distractors, our single-task MOT (change alone) involved trials where items changed colour but there was no need to click them. In dual-task MOT (change + click) participants tracked targets but they also used the computer mouse to click *any* item that changed colour during the item motion phase of the tracking trial. The independent variables were task load (single-task MOT: change alone; dual-task MOT: change + click), number of targets (2, 3), and the identity of the item that changed colour (whether it was a target or distractor in MOT). Both the percentage of correctly reported targets in MOT and latencies to click any item that changed colour were measured.

Based on Terry and Trick (2021) we predicted that there would be general interference: the percentage of correctly identified targets in MOT should be lower in the dual-task MOT (change + click) than single-task MOT (change alone). This was to be expected given that both clicking items and MOT make demands on general working memory/sustained attention, as do non-manual tasks (e.g., phone conversation: Kunar et al., 2008). However, we also predicted differential interference, with performance worse when participants clicked distractors rather than targets (i.e., higher latencies to click items that changed colour, lower accuracy MOT).

2. Method

2.1. Participants

51 participants were recruited from the university listserv ($n_{male} = 12$, $n_{female} = 39$, $M_{age} = 25.25$, $SE_{age} = 0.60$) and received $10 for their participation. An *a priori* sample size estimate determined that approximately 40 participants would be required to detect effects similar to those seen in past research (e.g., Terry and Trick, 2021). However, because we anticipated technical difficulties with online testing, we tested 11 additional participants.

2.2. Stimuli

The software used to present stimuli and collect response data was custom coded in JavaScript and hosted via the *Pavlovia* online data collection system. Participants were tested on their own computers. The "*Catch the Spies*" variant of the MOT task was used (Trick et al., 2005). The task involved keeping track of the positions of spies (the targets: nefarious black hatted characters) that had disguised themselves to look like the rest of the population (distractors: green happy faces). Diameters for both the spies and happy faces was 13.96 mm (52 pixels). Objects moved over a 126.00 × 194.38 mm black area on the computer screen (the tracking field).

Each trial progressed through *trial setup, initialization, target assignment, motion*, and *target report* phases (see Fig. 1). During *trial setup,* participants were prompted to move their mouse (the cursor) to a "mouse home" box (13 × 25 mm) at the bottom of the screen. The *initialization phase* then began: 10 green happy faces appeared in random positions on the tracking field. Next, during *target assignment*, the spies (targets) would reveal themselves: 2–3 green happy faces switched back and forth from happy-face to spy form to indicate that they were targets over a period of 5 s. Then all became green happy faces again.

During the *motion phase*, the green happy faces moved randomly and independently for 10 s, moving at a speed of 25 mm per second. Objects would "bounce off" each other if they collided. On two separate occasions during the *motion phase*, a happy face would change from green to orange. The first change was 1.5 −3 s after motion onset and the second was 6–7.5 second after motion onset. A different randomly chosen face would change colour every time (changing items were either targets or distractors).

It was in the *motion phase* that the differences between single-and dual-task conditions occurred. In single-task MOT (change alone) trials, participants did not have to click items that changed colour. A selected happy face would turn orange and then change back to green after 2 s. Participants were instructed to keep the mouse in a home box at the bottom of the screen for trial duration. (If the participant moved the mouse, a warning would appear on screen and the trial would restart.)

In dual-task MOT (change + click) trials, participants tracked the targets, but they also clicked any item that changed colour as quickly as they could using the mouse. When a colour change occurred, the happy face would remain orange for a maximum of 2 s but would change back to green as soon as it was clicked. If a participant did not click the item within 2 s a warning was posted and the trial began again. Between clicks, participants had to return their mouse to its home within 2.5 s or a warning would appear and the trial would restart.

The *target report phase* was the same in every condition. The green happy faces stopped moving and participants used the mouse to click the green happy faces that they believed to be targets (spies) at their leisure, clicking as many items as there were targets. After they made their choices there was feedback (the spies revealed themselves for 1.5 s).

2.3. Procedure

Participants were instructed to seat themselves within arm's length of their computer screens. At the beginning of the computer task participants completed a credit card task (Li et al., 2020) to ensure the dimensions of the tracking field and stimuli remained consistent regardless of the dimensions of their own computer screen. All participants started with eight practice trials of the single-task MOT (change alone) to familiarize themselves with the MOT task before attempting the dual-task MOT (change + click). They then did two blocks of trials (single-task MOT, dual-task MOT) in counterbalanced order, with the identity of the item that changed colour (target, distractor) randomized within each block. There were 104 trials total (8 initial practice trials plus 8 practice and 40 experimental trials per block). The study took an hour.

3. Results and discussion

To determine whether there was differential interference between mouse-clicks on items that change colour and MOT, both MOT performance and mouse click latencies were measured. To caution against violations of the sphericity assumption, the Greenhouse-Geisser correction was applied. Bonferroni tests were used for post-hoc tests of means.

3.1. Do mouse-clicks on items that change colour interfere with MOT?

MOT performance was measured as the percentage of correctly identified targets (e.g., one of two targets correct = 50%). Data from two participants were dropped because MOT performance was 3–5 standard

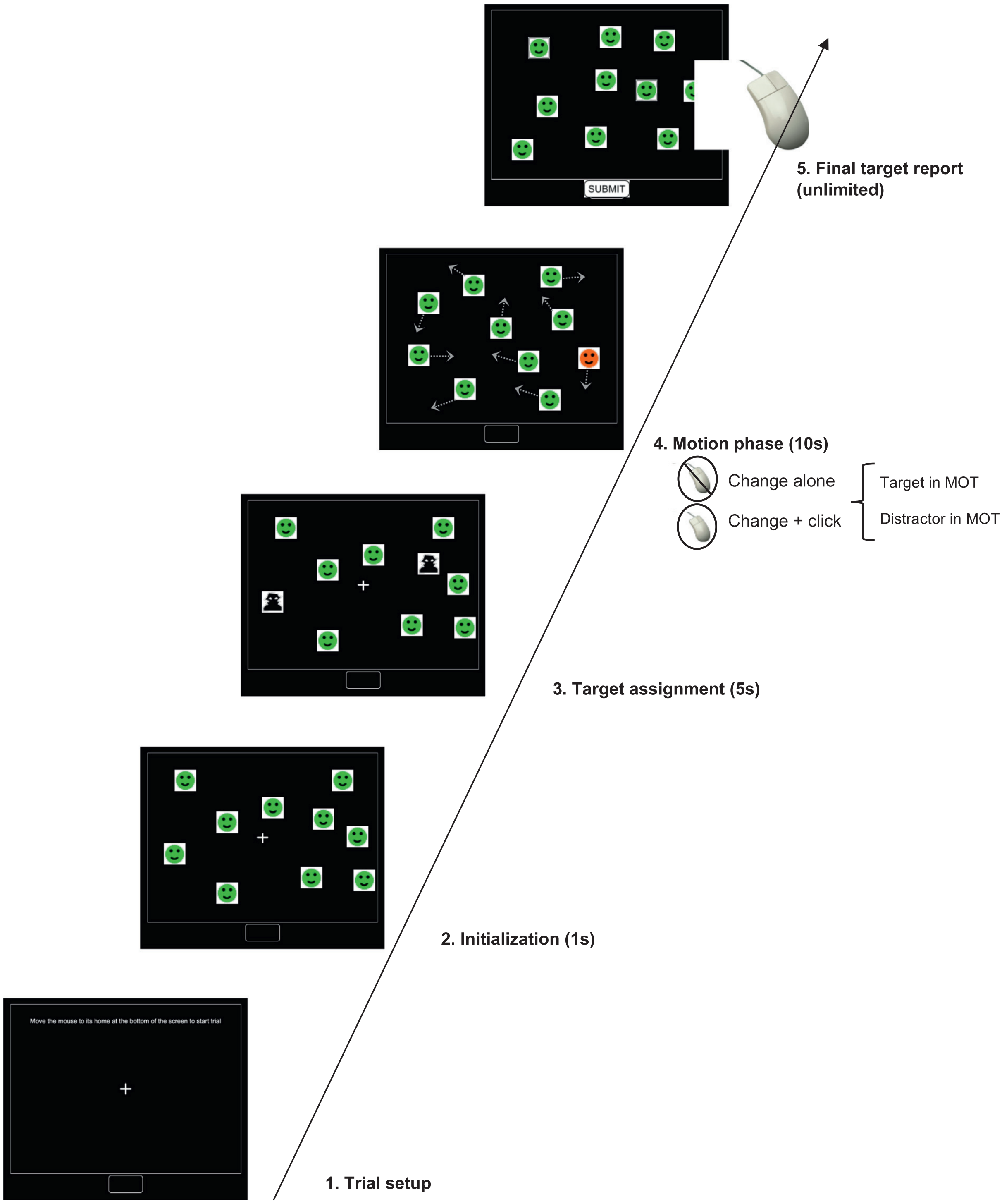

Fig. 1. Phases within each trial of the task.

deviations below the mean in all conditions; sample size was consequently 49 for these analyses. To begin, to ensure that the identity of the item that changed colour (target, distractor) had no effect when there was no need to click the item, we analysed single-task performance in isolation. There was no effect of identity or identity X number of target interaction ($p > .05$ for both). This indicates that the item that changed colour during item motion had no effect when there was no need to click them with the mouse.

A factorial repeated measures ANOVA was then performed with task load (single-task MOT (change alone); dual-task MOT (change + click), number of targets (2, 3), and identity of the item that changed colour during motion (target, distractor in MOT) as factors. See Fig. 2. As predicted, there was evidence of differential interference in MOT; a task load x item identity interaction emerged, $F(1,48) = 45.67$, $p < .001$, $\eta^2_p = 0.48$, with item identity having a stronger effect when participants had to click the items. There was also the usual decrease in the number of correctly reported targets with increases in the number to be tracked, $F(1,48) = 21.21$, $p < .001$, $\eta^2_p = 0.31$. A task load x number of targets interaction emerged as well, with the amount of interference increasing with the number targets to track, $F(1,48) = 10.91$, $p = .002$, $\eta^2_p = 0.19$. To clarify these effects, interference between tasks (single task minus dual-task performance) is graphed in Fig. 3, illustrating the larger dual-task decrement in tracking accuracy when clicking on distractors as compared to targets.

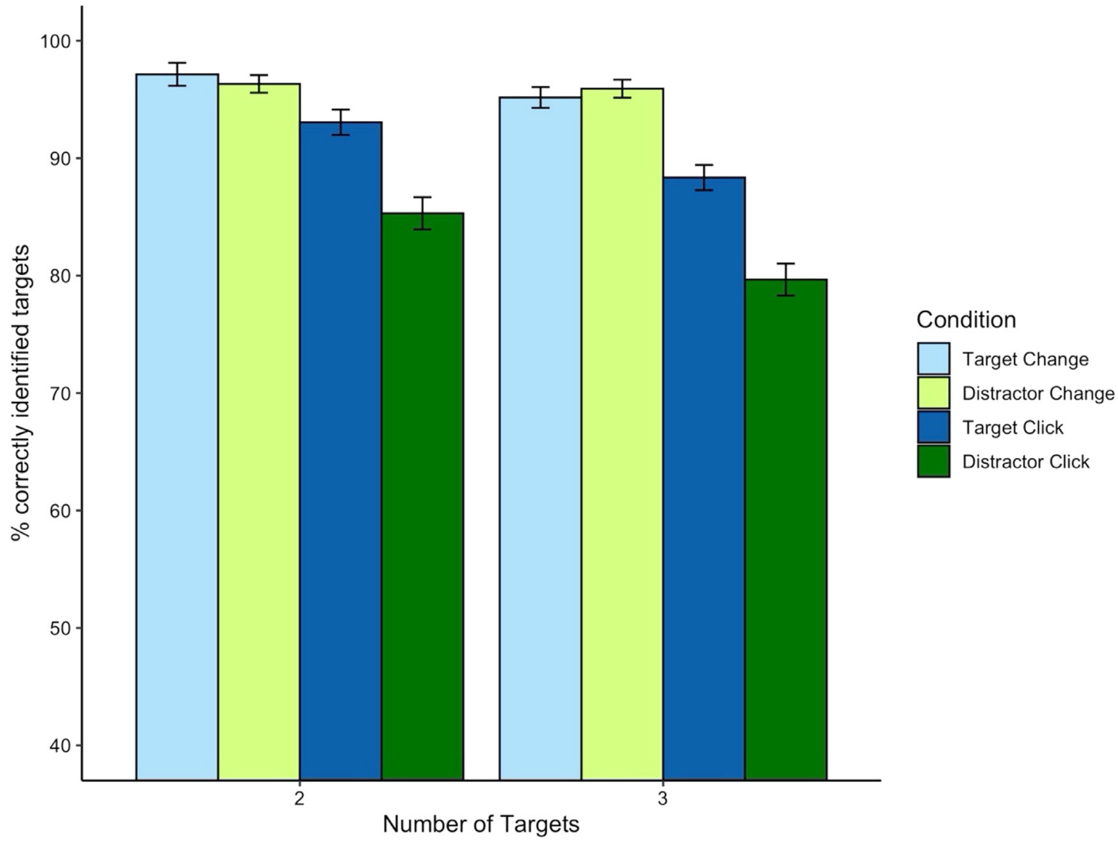

Fig. 2. Percentage of correctly identified targets in multiple-object tracking as a function of task load (single task MOT/change alone; dual task MOT/ change + click), number of targets (2, 3), and the identity of the item that changed colour (target, distractor in MOT).

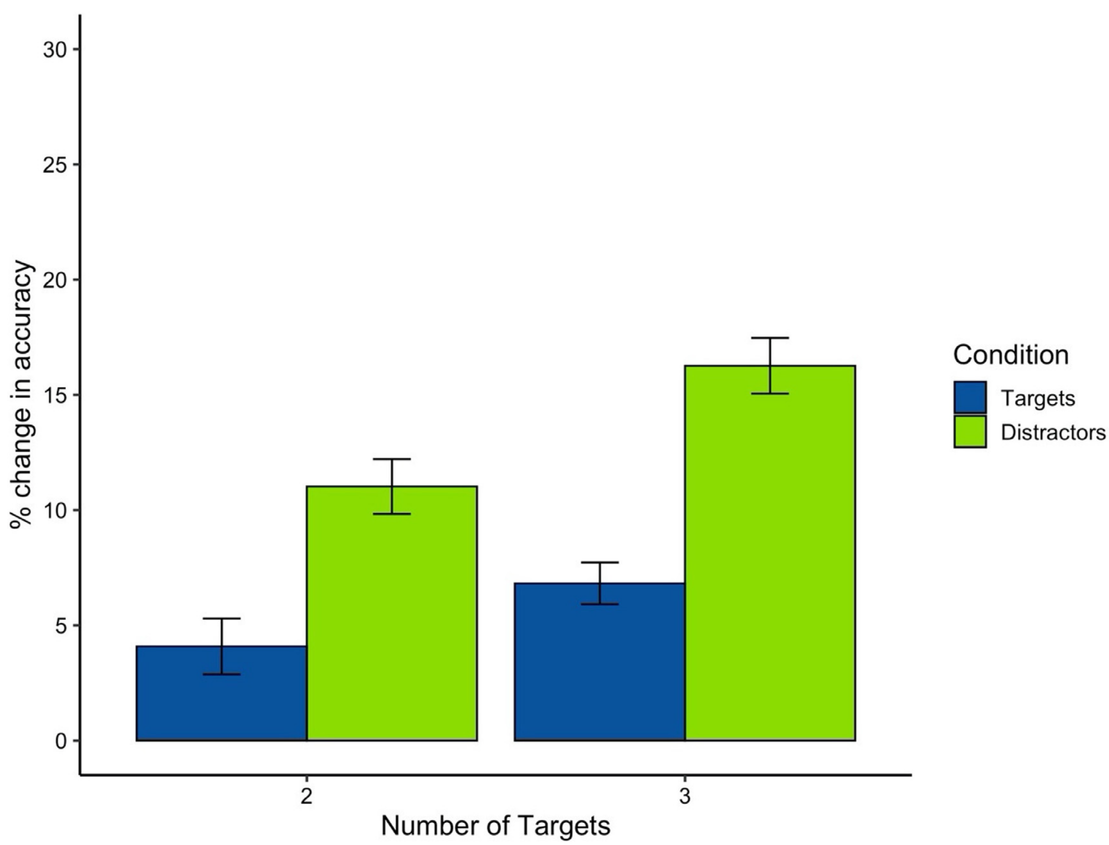

Fig. 3. Interference as measured by the change in the percentage of correctly identified targets (single- minus dual-task performance) as a function of the identity of the item that changed colour (target, distractor in MOT) and the number of targets (2,3).

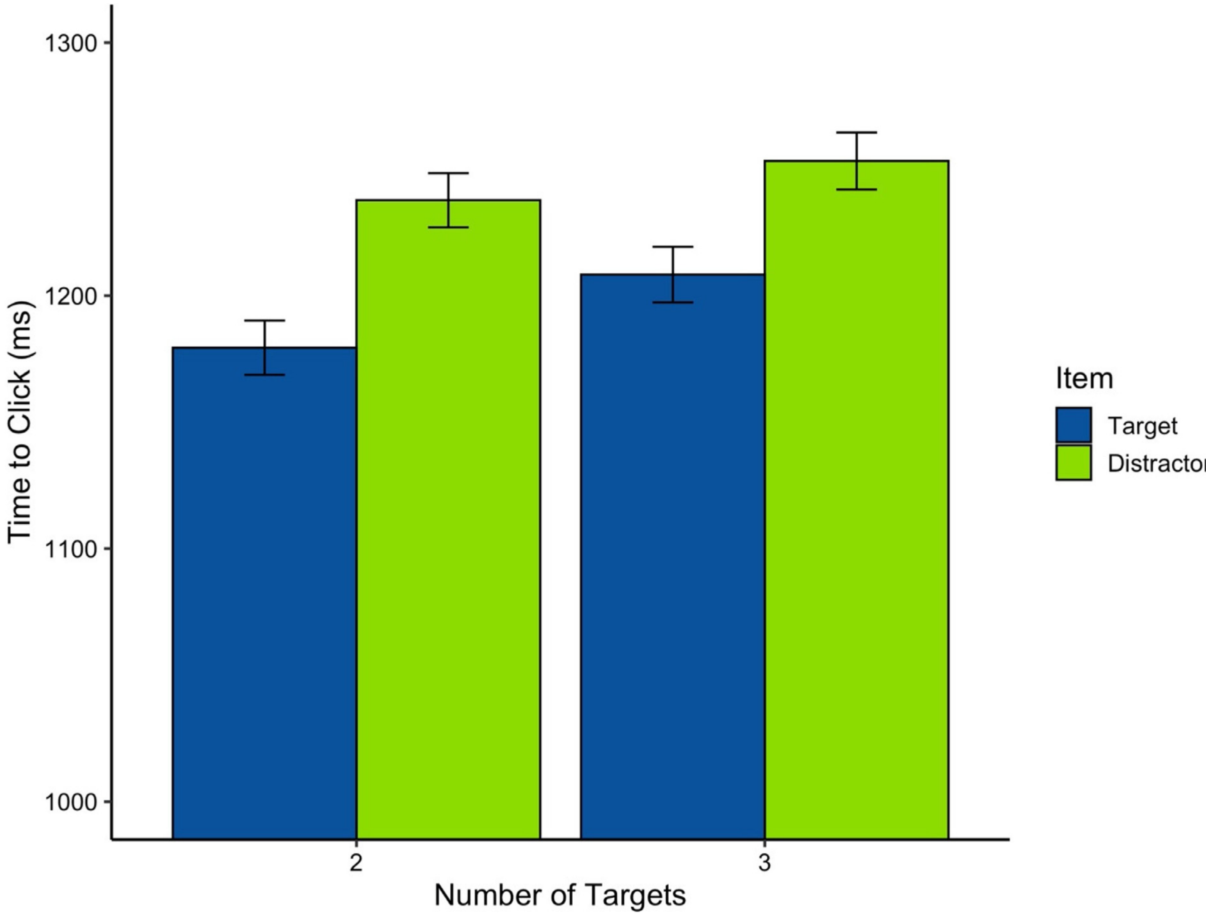

Fig. 4. Time to click items that changed colour in milliseconds as a function of the identity of the item that changed colour (target or distractor in MOT) and the number of targets (2,3).

3.2. Does MOT interfere with mouse-clicks to moving items that changed colour?

Participants were 100% accurate when using the mouse to click the item that changed colour during item movement. Mouse-click performance was measured in terms of the average RT to click each item that changed colour (there were 2 clicks per trial). It would be misleading to include RT to click items that were targets in MOT if the participants considered them distractors based on their final report. Similarly, it would be misleading to include RT to click items that were distractors in MOT if the participants considered them targets based on their final report. Consequently, latencies to click individual items (targets or distractors) were only included if the participant was correct about that specific item in their final report of targets in MOT. Due to this restriction, data from an additional 2 participants were dropped from RT analyses because there were not enough remaining latencies to analyse in every condition. For the remaining data, for each participant, individual latencies were dropped if they fell outside 2.5 standard deviations of the mean for that participant in that specific condition (0.55% of the latencies were dropped).

To determine whether there was differential interference, ANOVAs were performed assessing the effect of item identity (target or distractor in MOT) and the number of targets (2,3) on the time to click items that changed colour (see Fig. 4). As predicted, there was evidence of differential interference. On average, participants took 47 ms longer to mouse-click an item that changed colour when the item was a distractor compared to a target in MOT, $F(1,45) = 35.01$, $p < .001$, $\eta^2_p = 0.44$. The number of targets also had an effect, $F(1,45) = 6.13$, $p = .017$, $\eta^2_p = 0.12$). The interaction was not significant ($p > .05$)

Taken together, these results confirm the findings from Terry and Trick (2021), as mouse-clicks interfered with MOT in the same way as direct finger-touch. Accuracies to track targets for the two studies were comparable. Furthermore, in both studies, response times for actions performed towards moving distractors were significantly higher than those performed towards moving targets, and the magnitudes of these differences were roughly similar. On average, in Terry and Trick (2021) latencies to touch distractors were 62 ms slower than latencies to touch targets ($p = .002$, $\eta^2_p = 0.25$), and 47 ms slower when clicking on distractors in the present study ($p < .001$, $\eta^2_p = 0.44$). The similarity of these effects was especially impressive given that one of the studies was conducted in the laboratory using specific iPads, and the other was conducted online (the present study) using a variety of different types of computers and mice.

However, direct comparisons between Terry and Trick (2021) and the present study must be made with caution. First, Terry and Trick (2021) utilized a more challenging MOT task with up to 4 targets in MOT instead of 2–3 in the present study. Moreover, in Terry and Trick (2021) when objects collided, they were allowed to pass in front of each other rather than bouncing off each other as occurred in the present study. Most important, in Terry and Trick (2021) testing was conducted in a laboratory under direct supervision of a researcher who could ensure participants followed directions. Direct supervision of this kind was impossible in the present (online) study. Although in the present experiment participants were instructed to keep their cursor on the home box throughout the tracking trial and their fingers off the display, it is possible that some may have used their fingers to aid in tracking objects during item motion, which may have facilitated tracking performance. However, there is reason to expect that this did not happen for most participants as performance was not at ceiling. Nonetheless, the best way to ensure that participants were not using their fingers to track targets in the present study is to conduct the experiment in a laboratory environment under the supervision of a researcher.

In the present study, MOT performance was significantly lower and time to click items that changed colour was significantly higher when the item clicked was a distractor as opposed to a target in MOT. Overall, these results not only suggest the idea that mouse-clicks and finger-touch make use of similar mechanisms, but they also support Pylyshyn's (2001) contention that the locational indices used for targets in MOT are also used in visually guided behaviours toward moving items (hence the advantage). Nonetheless, it is possible that participants move their eyes, hands, or head differently when in a standard MOT task as compared to when performing MOT while touching or clicking on items. The next steps for this line of research will involve the use of eye/ head tracking and kinematic analyses of movement trajectories for touching or clicking on moving items during MOT.

Data and code availability

In the event that the article is published we have set up a Data Repository with the University of Guelph to make the raw data accessible https://doi.org/10.5683/SP3/LUVBNJ. The link is not currently active but this is where the raw data would be accessed in the event that the article is published.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Lana M. Trick reports financial support was provided by Natural Sciences and Engineering Research Council of Canada.

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