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Action matters! Target report technique affects interference between visually guided touch and multiple-object tracking

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ABSTRACT
When participants carry out concurrent tasks there can be overlap in action plans. This study shows the effects of action-plan overlap in a multiple-object tracking (MOT) task where participants tracked 1–4 targets while touching any items that changed colour during the item motion phase of tracking trial (either targets or distractors in MOT). We manipulated the way that participants reported MOT targets at the end of the trial. Participants (untimed) either reported targets by touching them with the index finger of their dominant hand (maximal overlap between target report and touching items that changed colour) or typed in letters corresponding to targets with their non-dominant hand (minimal overlap). Target report had no effect on single-task MOT performance. However, when participants had to touch items that changed colour during tracking, MOT was significantly worse when participants reported targets by typing them in rather than touching them and it also took participants longer to touch items that changed colour even though these colour changes preceded target report by 7–8 s. Nonetheless, target-report did not affect the performance discrepancy between the target- and distractor-touch conditions, which suggests performance differences between these two conditions reflect differences in attentional selection rather than action-plan overlap.

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Multiple-object tracking; action plans; dual-task interference; attentional tracking; visually guided touch

When two tasks are performed concurrently they often interfere with one another, which is to say that performance on one or both tasks is worse than when the two tasks are performed in isolation (e.g., Pashler, 1998). This dual-task interference is primarily thought to occur because both tasks occur at the *same time* and place demands on limited cognitive resources such as attention or working memory (e.g., Allen et al., 2004; Kunar et al., 2008). However, carrying out two different tasks also requires executing two different action plans: plans for carrying out specific motor responses at specific locations and times. Evidence suggests that overlap between action plans can either improve or degrade performance even when the responses are executed one after another, which may be evidence that storing and coordinating plans for controlled actions puts demands on working memory (see Fournier et al., 2015 for a review). In this study we investigated the impact of action-plan overlap on the interference between multiple-object tracking (MOT) and visually guided touch. We were interested in whether the degree of overlap between action plans required for touching moving items that changed colour during the item motion phase of MOT and later reporting the identity of MOT targets influenced performance.

MOT involves monitoring the positions of multiple target items as they move among identical distractors (Pylyshyn & Storm, 1988). Performance is measured using the MOT task, which involves presenting a number of identical items, having a subset flash to indicate they are targets (e.g., 1–4 of the 10 items presented), making the items identical once again, setting them into random independent motion for a period of time (e.g., 10 s), and finally having the participants report the positions of the targets. Display parameters affect MOT performance but most young adults can track 3–4 items at once (for a review, see Meyerhoff et al., 2017).

Pylyshyn (1989) proposed that the mental mechanisms used in the MOT task were integral to visually guided actions that we perform daily, such as touching specific items among others. Terry and Trick (2021) tested this assumption in a dual-task study

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where participants performed two independent tasks: MOT and touching any item in the display that changed colour during the item motion phase of MOT (visually guided touch). They found that the two tasks interfered with one another; MOT performance was worse and latencies to touch items that changed colour were higher when the two tasks were performed concurrently rather than in isolation (cf., Styrkowiec & Chrzanowska, 2018; Thornton & Horowitz, 2015). However, this interference was differential, with better MOT performance and lower touch latencies when the touched items were targets rather than distractors in MOT. Although there were no differences in single-task MOT based on whether the items that changed colour during the item motion phase of the tracking trial were targets or distractors, differences emerged when participants had to touch those items during MOT (Terry & Trick, 2021, 2022).

This differential interference could originate from two sources. From the perspective of Pylyshyn's theory (1989), this result could be interpreted as evidence that the two tasks share the same selection mechanism: there was an advantage when the same item was selected for the two tasks even though the tasks were independent and the task that required touching items that changed colour occurred seconds before the final report of the targets in MOT. However, in Terry and Trick (2021) participants indicated the items that changed colour during item motion by touching the item and later reported the positions of the targets in MOT in the same way. Thus, the action plans for the two tasks overlapped: the same effector (the index finger in the dominant hand) was used to touch items and later report the target items at the end of the trial. Nonetheless, the amount of overlap might be expected to differ in the target- and distractor-touch conditions. In the target-touch condition, targets changed colour and were touched, thus participants used the *same action* (touch) to respond to the *same items* that later had to be reported as targets in MOT. That would represent maximal overlap – at least if action plans used dynamic object-based coordinates rather than coordinates for specific static locations (e.g., see Scholl, 2001). The spatial location that participants touched when they touched a target that changed colour during item motion would always be different than the location they touched when reporting the target for MOT at the end of the trial, but that touch would correspond to the "same one" as represented in object-based coordinates. In contrast, there was only partial overlap in the Distractor-touch condition (*same action*, *different item touched*). Partial overlap in action plans can impede performance in deliberate controlled actions (e.g., see Fournier et al., 2015 for a review) and this might contribute to poor performance in the distractor-touch condition.

To investigate whether differences in action-plan overlap caused the difference between the target- and distractor-touch conditions, we manipulated how participants reported the identity of MOT targets at the end of the trial, incorporating a condition where the action-plan overlap between touching items that changed colour and later reporting MOT targets would be minimal in both the target- and distractor-touch conditions. Participants tracked 1–4 targets and then reported the identity of all targets at the end of the trial at their leisure (untimed). In the tracking + touch conditions, during item motion participants also had to touch any items that changed colour with the index finger of their dominant hand. We then compared performance when target report involved touching targets with the index finger of the dominant hand (maximal overlap, though perhaps more overlap for targets than distractors) to that when participants reported targets by typing in letters corresponding to targets on a keyboard using their non-dominant hand (minimal overlap for both targets and distractors). Extrapolating from the action plan literature, which typically focuses on actions directed towards static locations (e.g., see Fournier et al., 2015 for a review), we predicted that if the observed difference in performance between the target- and distractor-touch conditions was either fully or partially due to differences in action-plan overlap, then the size of the difference between target- and distractor-touch conditions (the differential interference) would decrease when overlap between the two actions was minimized and participants used a keyboard to type in the letters corresponding to MOT targets. That is because in both target- and distractor-touch conditions participants would be touching keyboard keys rather the objects they touched and tracked on the screen (different actions, different objects).

Method

Participants

Participants were students at the University of Guelph with normal or corrected to normal vision ($n = 81$, 7 left-handed). Of those, 42 were in the touch report condition (29 female, $M_{age} = 22.00$, recruited from list-servs and paid \$10 for participating) and 39 were in the typing report condition (31 female, $M_{age} = 18.41$, recruited from a participant pool and paid in course credit).

Design

There were four factors. MOT target report (touch, type) was the sole between-subjects factor. Task load (track alone, track + touch) and the number of targets to be tracked at once (1–4) were within-subjects factors. A fourth factor was nested within the track + touch condition: participants either touched targets or distractors. MOT performance was measured as the percentage of correctly identified targets at the end of the trial (e.g., 3 correctly reported targets out of 4 = 75%). In the tracking + touch condition latencies to touch the first item that changed colour were also measured.

Apparatus and stimuli

The study involved a 20 × 15 cm *iPad* touch screen tablet attached to an external keyboard. Participants sat 50 cm from the iPad and completed the *Catch the Spies* MOT task (Trick et al., 2005) in which they were instructed to monitor the changing locations of a number of targets (spies) on the screen that had disguised themselves as regular people (distractors: happy faces). These items appeared within a black rectangular tracking field occupying approximately 22 × 17° visual angle on the screen. A 1.72° × 3.44° "home box" was drawn on the bottom of the screen. Participants were always required to keep index finger of their dominant hand in the "home box" when not touching items that changed colour or reporting targets.

Each trial had four phases (see Figure 1). *The initialization phase* began when participants placed their finger on the home box. Ten (1.50°) green stationary happy faces appeared at random locations in the tracking field. During the *target assignment* phase 1–4 (1.49°) black spies emerged from behind green happy faces for 5 s. The spies then hid behind the happy faces so that all items became identical (green happy faces) and the *motion phase* began. The 10 happy faces moved randomly and independently at an average speed of 2.3° per second for 10 s, bouncing off other items and the edge of the tracking field.

In the *track + touch* condition, on two different occasions during the item motion phase one of the items changed colour (green to orange). The first colour change occurred 2–3 s after motion onset; the second occurred 6–7 s after motion onset. Each colour change occurred on a different item of the same type, either both targets or both distractors. Trial types were randomly intermixed so participants could not anticipate what type of item would change colour from trial to trial. Participants were instructed to touch any item that changed colour as fast as they could with the index finger of their dominant hand, moving their finger from the home box to the item that changed colour and then returning their finger back to the home box. Once touched, the item changed back to its original colour (green). Although there were two touches per trial, only latencies for the first were analysed to avoid repeated touches of the same item. Trials were aborted and restarted with a different item configuration if the participant lifted their finger off the home button before the item changed colour, failed to return their finger to the home button between touches, or took longer than 2 s to touch the item.

The *target report phase* began once item motion stopped. Participants reported the positions of all the targets in MOT at their leisure, though the method they used varied based on the target report condition. In the touch report condition, participants reported the targets by touching each of the happy faces that they believed to be targets using the index finger of their dominant hand. In the typing report condition, letters appeared over each happy face once item motion stopped and participants used their non-dominant hand to type in the letters corresponding to the items they believed to be targets on a computer keyboard.

Procedure

Participants completed two blocks of trials in a counterbalanced order. In the *track alone* block

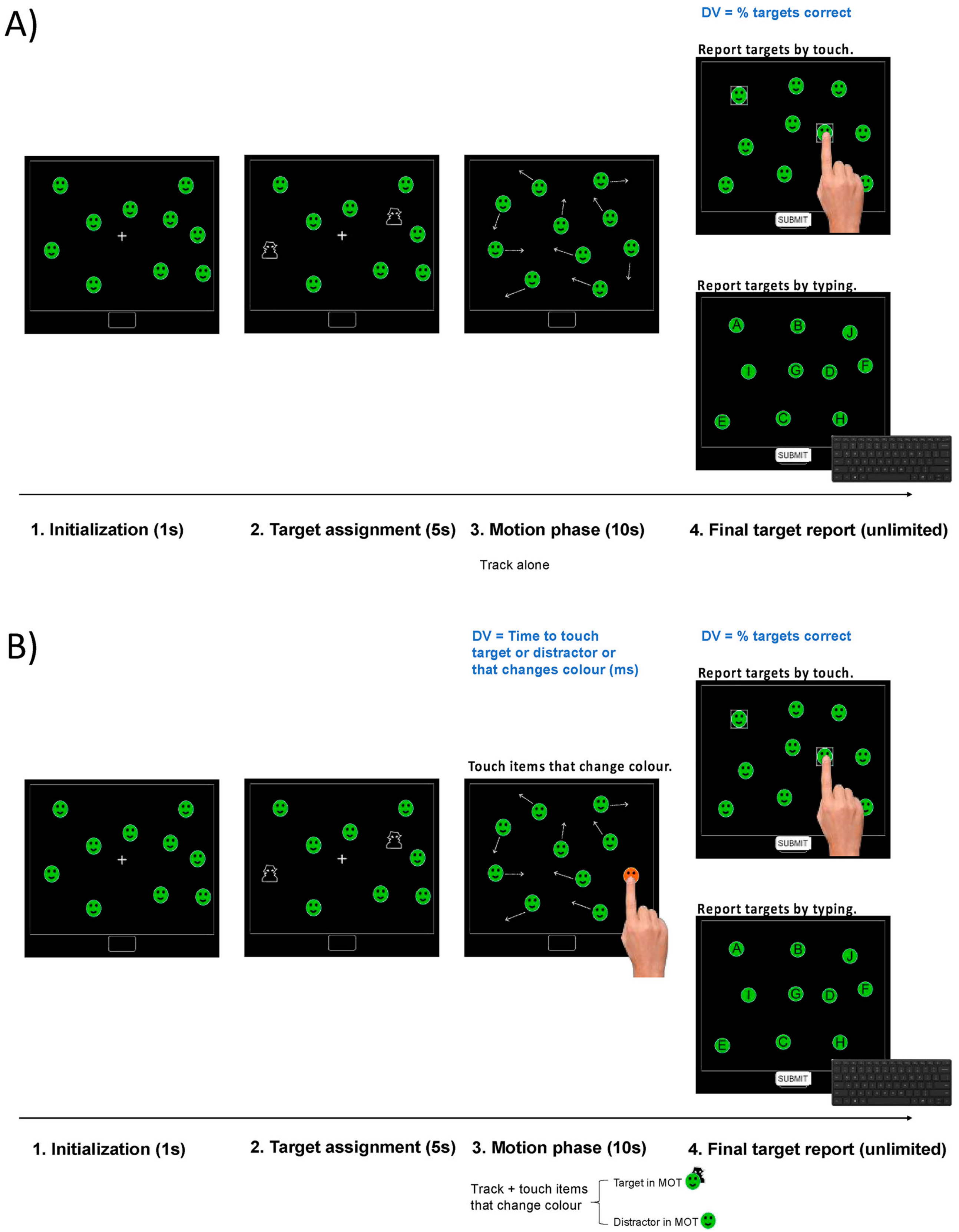

Figure 1. Participants completed the track alone (A) and track + touch (B) conditions in a counterbalanced order. During the final target report participants either reported targets by touching them or by typing in the letters on a keyboard corresponding to the targets.

participants only had to track; MOT performance was measured at the end of the trial (4 practice trials, 32 test trials). In the *track + touch* block, participants also had to touch items that changed colour and touch latencies were also measured (8 practice trials, 64 test trials: 32 for touch target, 32 for touch distractor).

Results and discussion

Four participants' data were dropped: one for not completing the experiment and three for having tracking performance more than 2.5 standard deviations below that of other participants. We begin with analyses of MOT performance and conclude with those on latencies to touch moving items that changed colour. Greenhouse-Geisser corrections were used against violations of the sphericity assumption.

MOT performance: The percentage of correctly identified targets

To start, we assessed the effects of target report (touch, type) in the *track alone condition*. As can be seen from Figure 2, target report had no effect on single-task tracking performance ($F < 1$). Performance declined with increases in the number of targets ($F(2.71, 203.03) = 34.09$, $p < .001$, $\eta_p^2 = .31$) as is typical in MOT studies but there was no interaction between target report type and the number of targets ($F < 1$).

To assess general interference, the number of correctly reported targets was analysed as a function of task load (track alone, track + touch), target report (touch, type) and the number of targets (1–4). As predicted, track + touch performance was significantly worse than in the track alone condition, indicating general interference ($F(1.00, 75.00) = 111.93$, $p < .001$, $\eta_p^2 = .60$, $M_{diff} = 7.00\%$). This interference increased with the number of targets (task load X number of targets: $F(2.87, 214.90) = 11.97$, $p < .001$, $\eta_p^2 = .14$; Bonferroni tests of means: 1 vs. 3 and 4: $p < .01$; 2 vs. 4: $p < .001$). Importantly, target report affected the amount of interference: the *difference* between track alone and track + touch performance was larger when participants typed in target items rather than touching them (target report X task load: $F(1.00, 75.00) = 7.16$, $p = .009$, $\eta_p^2 = .09$, $M_{diff} = 3.54\%$). Otherwise there were no significant effects (target report: $F(1.00, 75.00) = 2.71$, $p = .104$, $\eta_p^2 = .04$; target report X task load X number of targets: $F(2.87, 214.90) = 2.12$, $p = .099$, $\eta_p^2 = .03$).

Contrary to prediction, target report had no effect on differential interference though: the differences between the target- and distractor-touch conditions in track + touch condition (see Figure 3(a,b)). MOT performance was analysed as a function of the item touched (target, distractor in MOT), target report (touch, type), and number of targets tracked (1–4). Differential interference emerged as predicted (cf., Terry & Trick, 2021), with performance worse when the touched items were MOT distractors rather than targets ($F(1.00,75.00) = 65.24$, $p < .001$, $\eta_p^2 = .47$, $M_{diff} = 5.81\%$). Accuracy was significantly worse when the participants reported targets by typing them in ($F(1.00, 75.00) = 5.01$, $p = .028$, $\eta_p^2 = .06$, $M_{diff} = 3.29\%$) but the difference between target- and distractor-touch conditions was no smaller in the typing report condition, where there was minimal overlap in action plans, than where overlap was maximal (item touch report): $M_{diff} =$ 6.46% and 5.15% respectively, target report X item touched, $F < 1$. The three-way interaction was not significant ($F < 1$).

Touch latencies: The time required to touch the first item that changed colour

To investigate the impact of action-plan overlap on touch latencies, latencies to touch the first item that changed colour during the item motion phase were analysed as function of MOT target report (touch, type), the item that changed colour and was touched during item motion (target, distractor in MOT), and the number of targets to track (1–4). Notably, though participants had no time pressures when reporting the identity of targets at the end of the trial, the target report method that participants used had a significant effect on latencies to touch items that changed colour 7–8 s *earlier* in the trial, during the item motion phase of the MOT (see Figure 4). Latencies to touch items that changed colour were 48 ms higher when participants later reported targets by typing them in rather than touching them ($F(1.00, 75.00) = 4.50$, $p = .037$, $\eta_p^2 = .06$). There was no target report X number of targets interaction ($F < 1$).

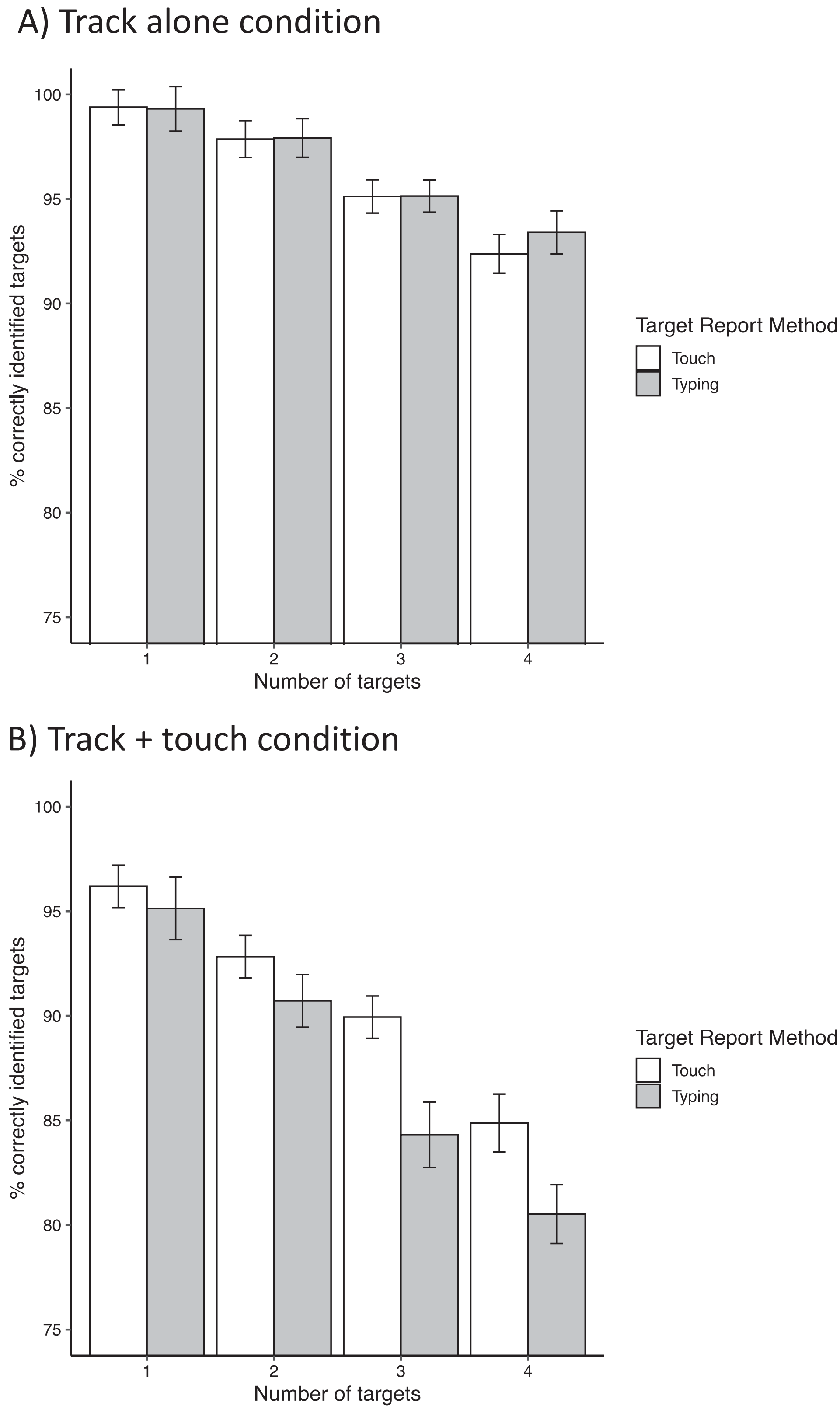

Figure 2. (A) Percentage of correctly identified targets in single task MOT (track alone) as a function of the target report method (touch, typing) and the number of targets to track (1–4). (B) Percentage of correctly identified targets in dual task MOT (track + touch – averaged across touch targets and touch distractor conditions) as a function of the target report method (touch, typing) and the number of targets to track (1–4). Error bars denote standard error. Report method (touch, typing) had no effect on single task MOT accuracy but had a significant effect in the dual-task (track + touch) condition.

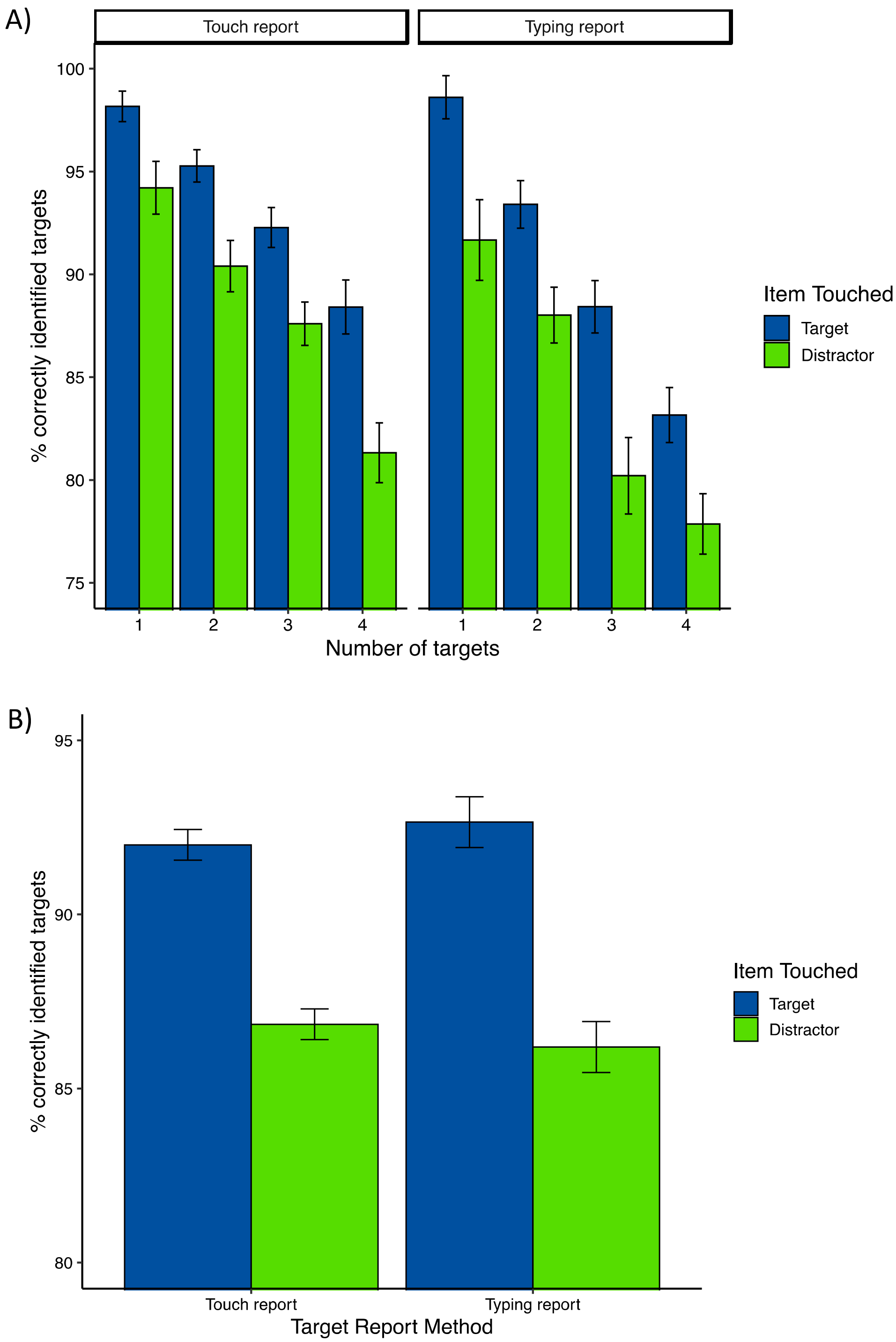

Figure 3. (A) Percentage of correctly identified targets in MOT as a function of the target report method (touch, type), the item touched during the item motion phase of MOT (target, distractor), and the number of targets to track (1–4). (B) Percentage of correctly identified targets in multiple-object tracking averaged across 1–4 targets as a function of the target report method (touch, typing) and the item touched during item motion (target, distractor). Report technique had a small but significant effect on overall MOT accuracy, with worse performance in the typing condition. However, MOT accuracy was always significantly better when participants touched items that were targets rather than distractors during the item motion phase of the tracking trial regardless of the way participants reported targets at the end of the trial.

Differential interference emerged as predicted; participants took 55 ms longer to touch items that changed colour when they were distractors rather than targets in MOT ($F(1.00, 75.00) = 68.58$, $p < .001$, $\eta_p^2 = .48$) but, contrary to prediction, target report had no effect on the amount of differential

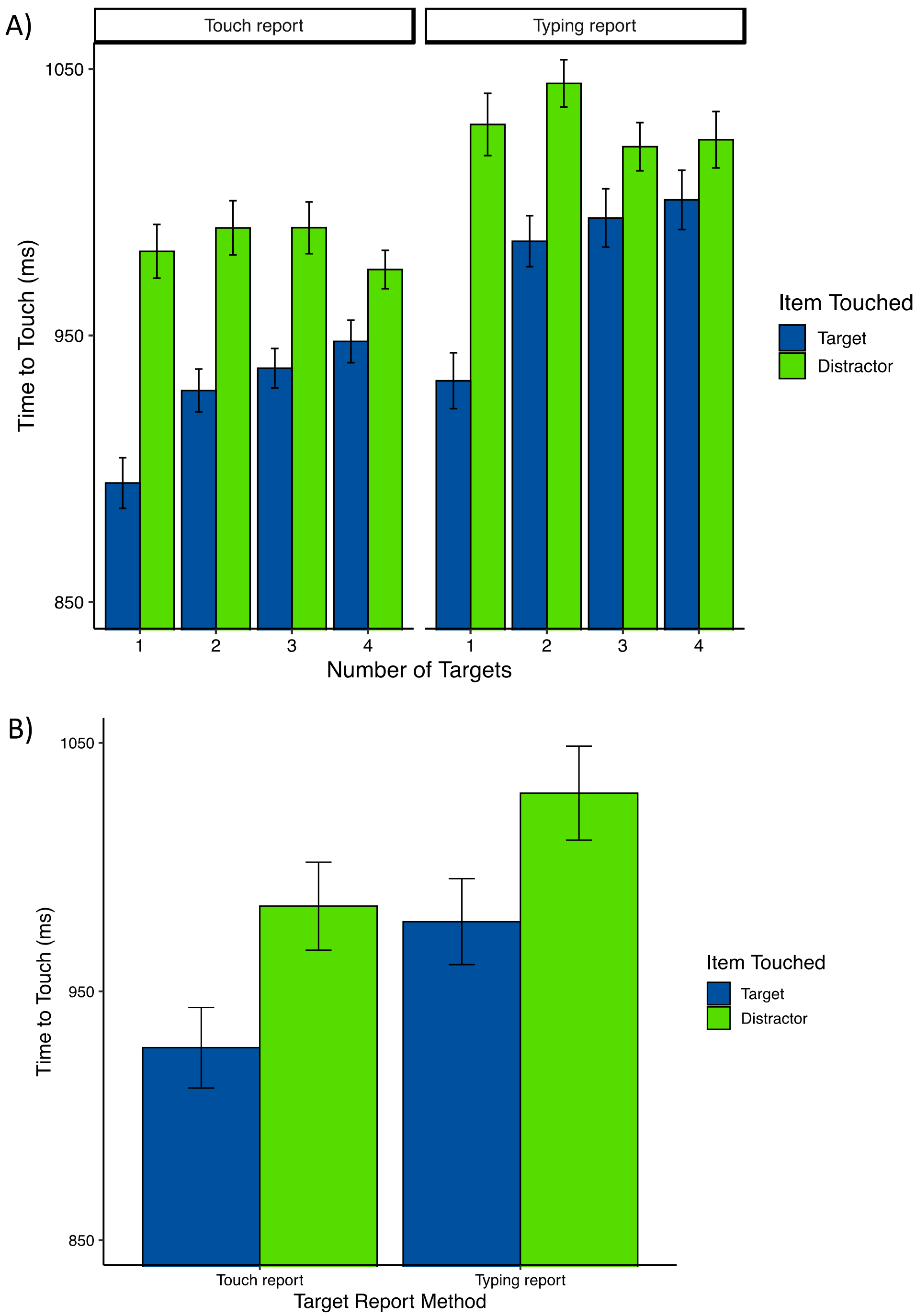

Figure 4. (A) Time to touch items that changed colour (milliseconds) as a function of the target report method (touch, typing), the item touched during the item motion phase of multiple-object tracking (target, distractor), and the number of targets to track (1–4). (B) Time to touch items that changed colour during the item motion phase (averaged across 1–4 targets) as a function of the target report method (touch, typing) and item touched (target, distractor). Error bars represent standard error. Overall, participants took significantly longer to touch moving items that changed colour when they later reported MOT targets at the end of the trial by typing them in rather than touching them. Nonetheless, it always took significantly longer to touch distractors than targets during item motion, regardless of the way participants reported targets at the end of the trial.

interference observed ($M_{diff} = 59.30$ and 50.93 ms for the typing and touch report conditions respectively; target report X item: $F < 1$).

Overall, these results suggest that although single-task MOT performance was no worse when participants reported MOT targets by typing them in rather than touching them, there was significantly more dual-task interference between touching items that changed colour and MOT when there was little overlap in action plans (the typing report condition).

Even though participants touched items that changed colour 7–8 s *before* the target report phase in MOT, participants took significantly longer to touch those items if they later identified MOT targets by typing them in (minimal overlap in action plans) rather than touching them (maximal overlap). The size of the discrepancy between target- and distractor-touch conditions was unaffected by target report though, as would be expected if it reflected differences in spatial selection (Pylyshyn, 1989) rather than differences in action-plan overlap.

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