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# Velocity cues improve visual search and multiple object tracking

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Early stages of visual processing are thought to rapidly extract a number of basic perceptual attributes from a visual stimulus, including object bound-

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aries, orientations, and colours, among others. One major topic of research in vision has been to specify which attributes can be extracted by this early stage of processing, and which attributes require limited capacity processing by later stages (e.g., Treisman & Gelade, 1980; Wolfe, 1994). Many previous studies have used visual search tasks to make this categorization. However, if an early processing stage exists, its output should be used by all later processes to perform any visual task.

In this paper, we seek evidence that basic attributes, thought to support the detection of a target in visual search, also facilitate segregation of targets from distractors when observers track a subset of randomly moving, identical objects—the multiple-object tracking (MOT) task. If a common stage of processing serves as input to both tasks, then objects with properties that are easy to search for should also be easy to track, while objects that are difficult to search for should be harder to track. We tested this prediction by comparing the results of a search experiment and an MOT experiment conducted on the same observers.

Here we investigated the role of speed. Ivry and Cohen (1992) performed a set of visual search experiments using oscillating dots. The target was a dot moving either slower or faster than the distractors. When targets moved more slowly than distractors, target-detection time increased as a function of the number of stimuli in each display ("set size"). However, when targets moved faster than distractors, target-detection time was minimally affected by set size. Thus, it is easier to find targets moving more quickly than distractors (i.e., they "pop out") than targets moving more slowly than distractors. It may be that this asymmetry is due to the way that the early stage computes velocity (Ivry & Cohen, 1992; Rosenholtz, 1999).

We hypothesized that an analogous asymmetry would be observed in MOT. That is, it should be easier to track targets that move more quickly than the distractors, compared to targets moving more slowly than distractors. This prediction might be somewhat counterintuitive. While it is easier to track targets that differ from distractors in speed (Yantis, 1992), all else being equal, tracking slower objects is easier than tracking fast objects (Alvarez & Franconeri, 2005).

We began by replicating Ivry and Cohen's (1992) visual search experiment. However, instead of oscillating stimuli, we used a motion pattern that could be compared to MOT. Stimuli were white disks measuring 1.33° visual angle with black borders. Disks were assigned random initial directions, then moved in straight lines, except when they bounced off the edges of the display ($20^\circ \times 20^\circ$). On 50% of the trials, one target disk moved at a different speed from the rest. Observers made a speeded detection response to either a fast (6.4°/s) target among slow (3.2°/s) distractors, or vice versa, in separate blocks.

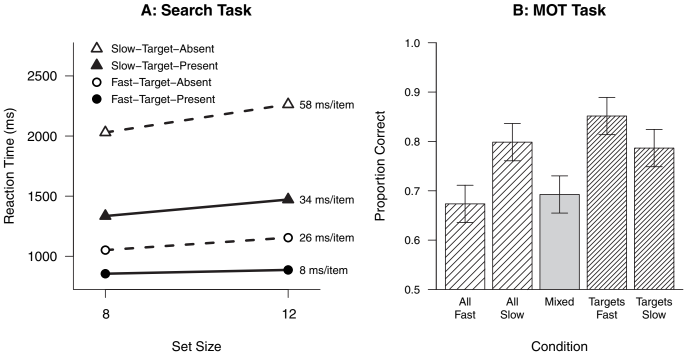

**Figure 1.** A: Correct reaction times (RTs) plotted as a function of display set-size for the visual search task. Triangles indicate slow-target trials and circles indicate fast-target trials; unfilled symbols indicate target-absent trials and filled symbols indicate target-present trials. Numbers to the right of each line show the slope of the RT by set-size function for the corresponding condition. The height of the plotting symbols indicates approximate 95% confidence intervals. B: Proportion of targets correctly recalled in each condition of the multiple object tracking (MOT) task. Error bars indicate approximate 95% confidence intervals.

The same observers then ran in a MOT task using identical stimuli. Observers tracked five targets out of 12 total disks (given an equal number of targets and distractors, observers might have cheated when target tracking was difficult by tracking distractors instead). There were five conditions in the MOT task: All stimuli moved fast ("all-fast"); all stimuli moved slow ("all-slow"); all targets moved fast and all distractors moved slow ("targets-fast"); all targets moved slow and all distractors moved fast ("targets-slow"); and a mixed condition in which the two speeds were evenly distributed among targets and distractors.

When targets and distractors are not completely identical, the observer might be tempted to not track at all, but simply use target-distractor differences to recover targets at the end of the trial. We took two precautions to thwart such a strategy. First, trial duration was unpredictable, varying randomly between 6 s and 8 s. Second, condition varied randomly from trial to trial, and observers were not informed of the speed manipulation.

Figure 1A shows a clear asymmetry between fast and slow targets in visual search, replicating the results of Ivry and Cohen (1992). Both the mean RTs and the slope of the RT by set size functions were smaller when the targets were faster. Our MOT results, shown in Figure 1B, replicated Yantis' (1992) finding that tracking was easier when targets and distractors could be discriminated by speed, as indicated by the difference between the mixed condition on the one hand, and the targets-fast and targets-slow conditions on the other, $F(1, 7) = 47.1, p < .001$. Tracking performance was better in the all-slow condition than in the all-fast condition, confirming that tracking difficulty increases with speed (Alvarez & Franconeri, 2005), $F(1, 7) = 44.9$, $p < .001$. However, when targets and distractors were segregated by speed, we observed the opposite pattern: Tracking performance was better in the targets-fast condition than in the targets-slow condition, $F(1, 7) = 11.9$, $p = .011$.

Thus, we observed an asymmetry in MOT analogous to the one observed in the visual search task. This asymmetry is predicted on the outcome of the search experiment even though previous results from MOT might seem to suggest that tracking fast targets should always be more difficult than tracking slow targets.

These results tentatively support the hypothesis that a common representation serves as input to search and MOT. This was not the only possible outcome. Texture segmentation and pop-out search were initially thought to tap into the same processes, but we now know that some attributes that support rapid texture segmentation do not support efficient search and vice versa (Wolfe, 1992). More work will be necessary to determine whether or not the same holds true for search and MOT, and whether or not MOT can serve as a tool for investigating the properties of early visual processing.

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