Supplemental materials for:

The influence of visual motion on fast reaching movements to a stationary object

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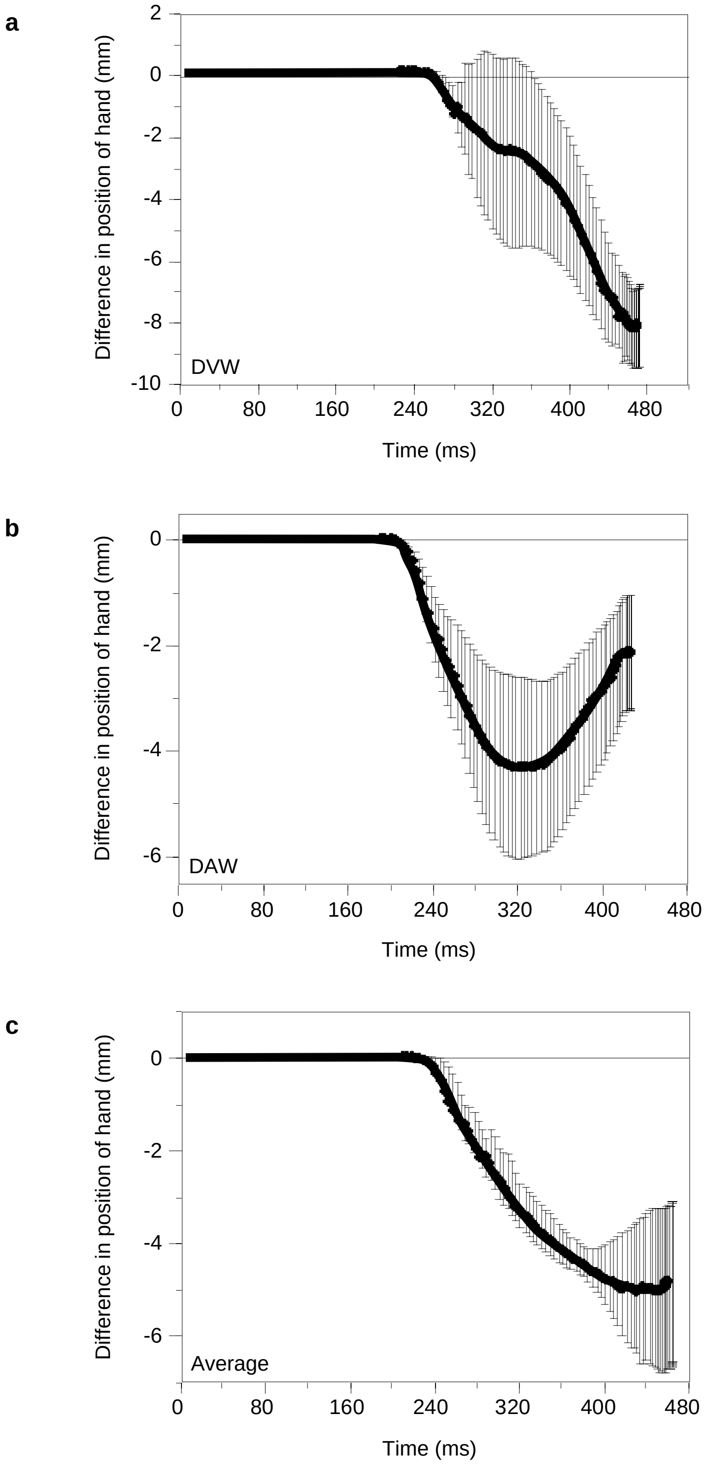
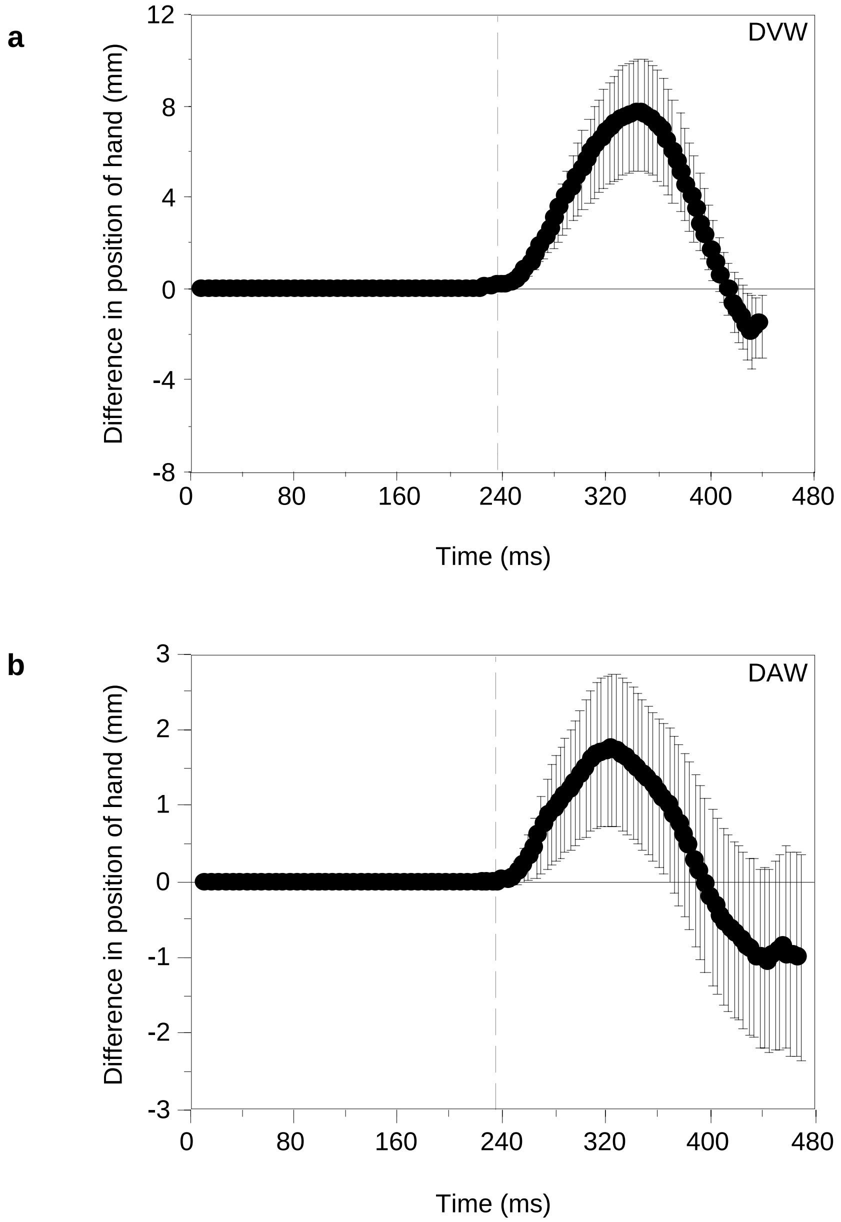
Supplemental Figure 1:



Supplemental Figure 1
Whitney, et al., 2003

Figure 1.S. Average deviation in the trajectory of the hand from experiment 1 for subjects DVW (**a**), DAW (**b**), and the average of all three subjects (**c**), where the target was presented coincidently with the motion reversal at 0 ms (as in Fig. 2b of the manuscript). The entire reaching movement was executed during unidirectional motion. Negative values on the ordinate indicate that the hand deviated in the direction of visual motion. There is a significant effect of visual motion on the hand's position as a function of time for DVW ($F_{(90, 180)} = 8.95$, $P < 0.001$), DAW ($F_{(74,518)} = 2.32$, $P < 0.001$), and the average of three subjects ($F_{(90,990)} = 7.54$, $P < 0.001$). Error bars, ±1 s.e.m.

Supplemental Figure 2:

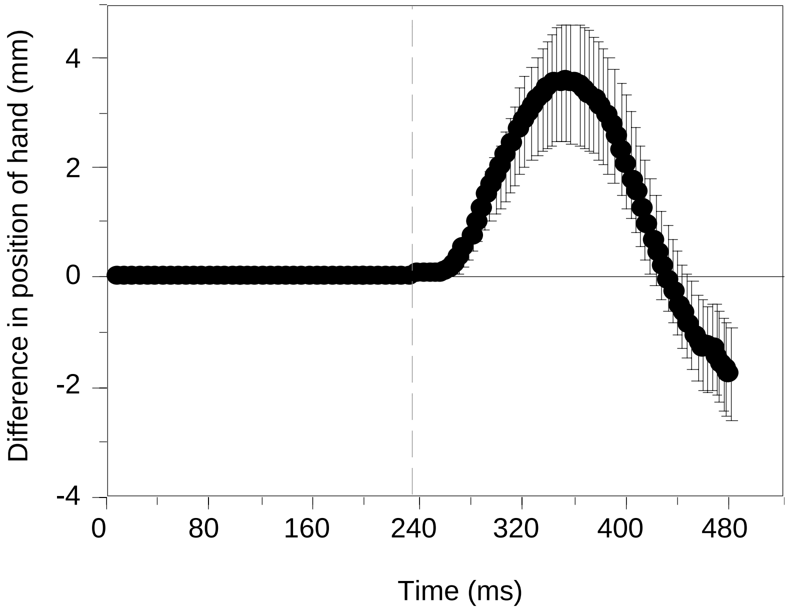


Supplemental Figure 2
Whitney, et al., 2003

Figure 2.S. Average deviation in the trajectory of the hand from experiment 1 for subjects DVW (**a**) and DAW (**b**), where the target was presented 235 ms before

the motion reversal (as in Fig. 3b of the manuscript). The target was presented at 0 ms. The vertical dashed line represents the motion reversal. The ordinate shows the shift in the hand's position over time. The data show that the hand's position began to deviate in the initial direction of motion (increasingly positive values), but eventually the hand was shifted in the opposite direction, consistent with the subsequent (reversed) direction of motion. There was a significant effect of the visual motion on the hand's position as a function of time for both DVW ($F_{(63,126)} = 3.63$, $P < 0.001$) and DAW ($F_{(66,462)} = 1.93$, $P < 0.001$). The minimum visuomotor delay, estimated by the peak of the deviation in the hand's trajectory, was 124 ms for DVW and 90 ms for DAW. The upper estimate of the visuomotor delay was 180 ms for DVW and 194 ms for DAW, based on the moment that the average deviation of the hand's position differs significantly from that estimated by the minimum visuomotor delay. An alternative method of calculating the visuomotor delay is to directly compare the trajectory of the hand when there is a motion reversal and when there is no reversal of motion (akin to previous methods[1,2]). The first significant difference in the trajectory of the hand for these two conditions was 148, 180, and 194 ms for subjects DAW, DVW, and ELV respectively, values that agree well with those estimated using the method above. Error bars, ±1 s.e.m.

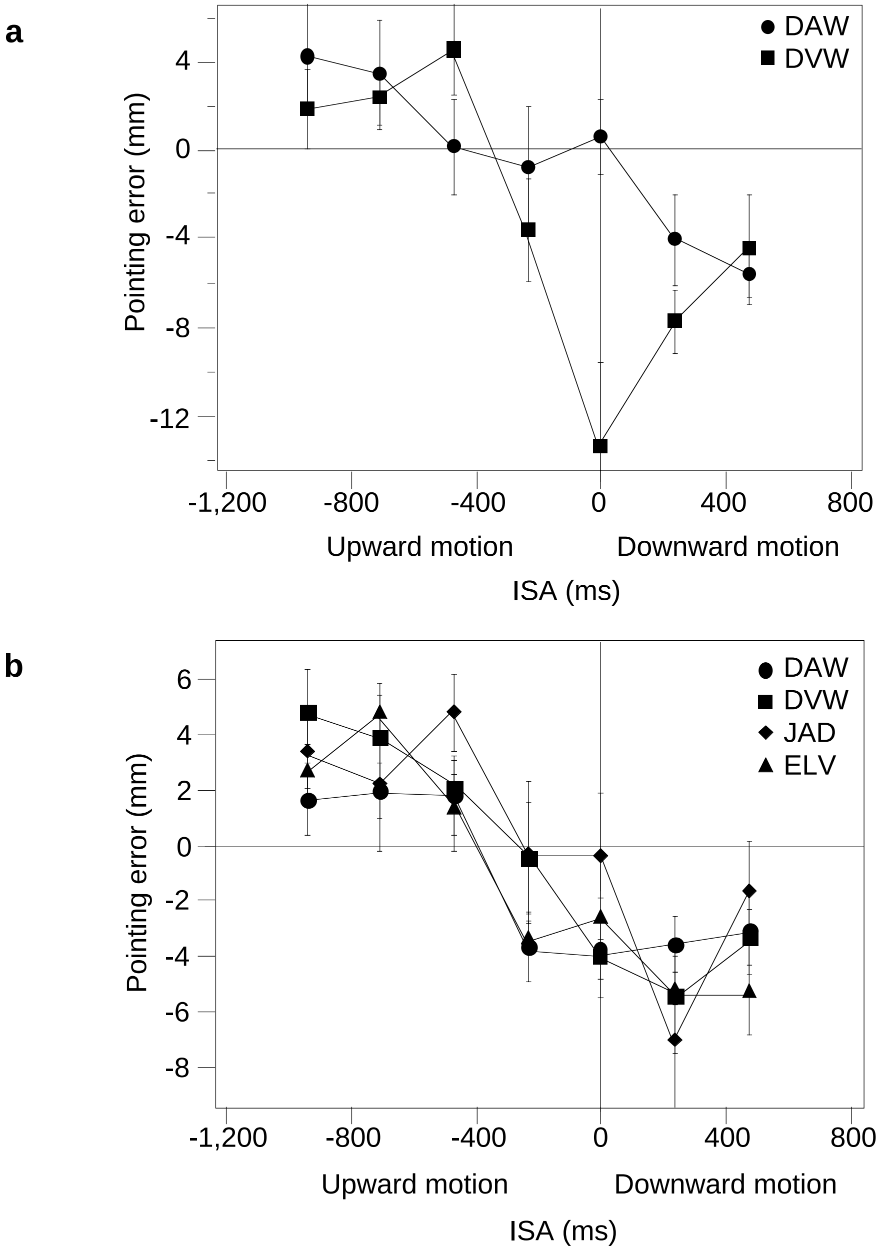
Supplemental Figure 3:



Supplemental Figure 3
Whitney, et al., 2003

Figure 3.S. Deviation in the trajectory of the hand from experiment 1 for subjects DVW, DAW, and ELV, averaged, where the target was presented 235 ms before the motion reversal (as in Fig. 3 of the manuscript). There was a significant deviation in the hand's position over time ($F_{(63,945)} = 10.5$, $P < 0.001$). The estimated visuomotor delay was 120-180 ms, comparable to the values estimated for each subject individually. Error bars, ±1 s.e.m.

Supplemental Figure 4:

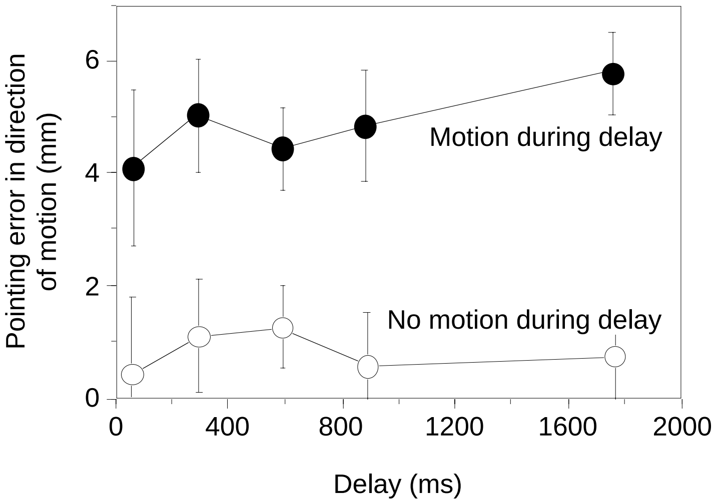


Supplemental Figure 4
Whitney, et al., 2003

Figure 4.S. The first experiment was repeated without vision of the hand. **a**. Results for two subjects when vision of the hand was prevented. To block vision

of the subject's limb during the reach, the stimuli on the CRT were reflected off a half-silvered mirror that was located at a 45° angle to the subject's body. Subjects rested their right arms on the far side of the mirror (rendering their arm invisible since the mirror blocked the view) and pointed to the apparent location of the target as seen in the mirror. A second, dummy CRT was provided behind the mirror to provide haptic feedback. There was a significant deviation in the hand's position over time for subject DVW ($F_{(6,119)} = 7.6$, $P < 0.001$) and subject DAW ($F_{(6,119)} = 3.5$, $P < 0.005$). **b**. Results from the first experiment, when vision of the hand was available, for comparison. There was not a significant difference between the results in (**a**) and (**b**) for subject DVW ($F_{(6,196)} = 1.3$, $P = 0.25$) or for subject DAW ($F_{(6,280)} = 1.9$, $P = 0.08$). Error bars, ±1 s.e.m.

Supplemental Figure 5:



Supplemental Figure 5
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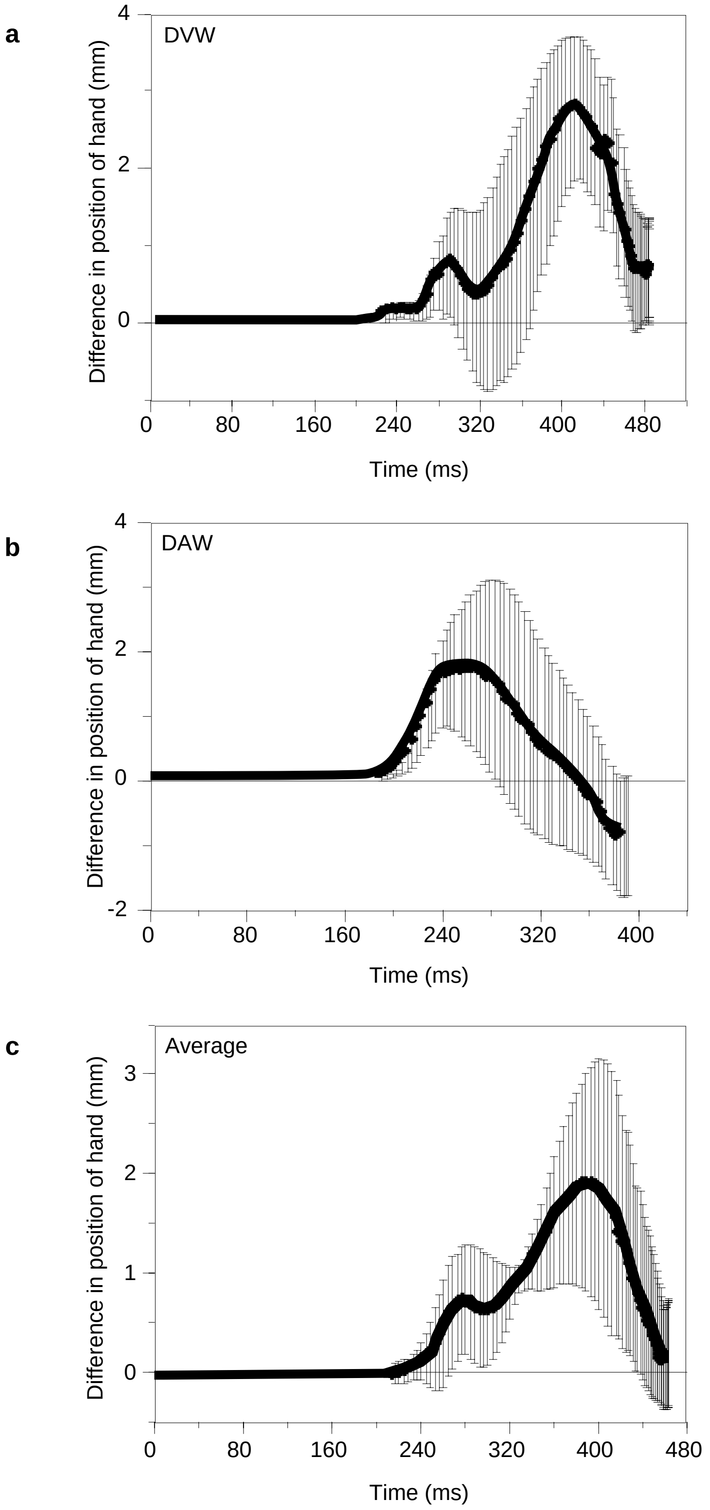
Figure 5.S. Average results for three subjects when reaching to the target was delayed. To delay reaching movements, subjects were instructed to wait for an audible tone serving as a “go” signal before responding; the go signal was delayed by one of five randomly determined values (along the abscissa). The moving grating either continued to move during the delay period or disappeared when the target was presented. This was to investigate whether the presence of motion during the reach is important. When motion was visible during the delay period, the endpoints of reaching movements continued to be biased in the direction of the motion (solid circles). When there was no motion visible during the delay period, there was a significant reduction in the bias (least significant difference was for ELV, $t_{(275)} = 8.58$, $P < 0.001$). There was no effect of the delay period, or any interaction, on the reaching movements ($P > 0.05$). To confirm that motion during the reach itself is important, we also tested a condition in which the moving grating was initially removed during the delay but then re-

presented just before the execution of the reach. Again, the hand was shifted in the direction of the nearby motion. The delay is therefore not critical for the influence of motion on position, contrary to some other types of visuomotor illusions[3]. The results indicated that as long as motion was visible during reaching movements, even to remembered targets, the reaching movements were biased in the direction of the motion. Just as eye and head movements can cause updating of remembered target position[4-7], the presence or removal of visual motion can trigger updating of target positions as well. Error bars, ±1 s.e.m.

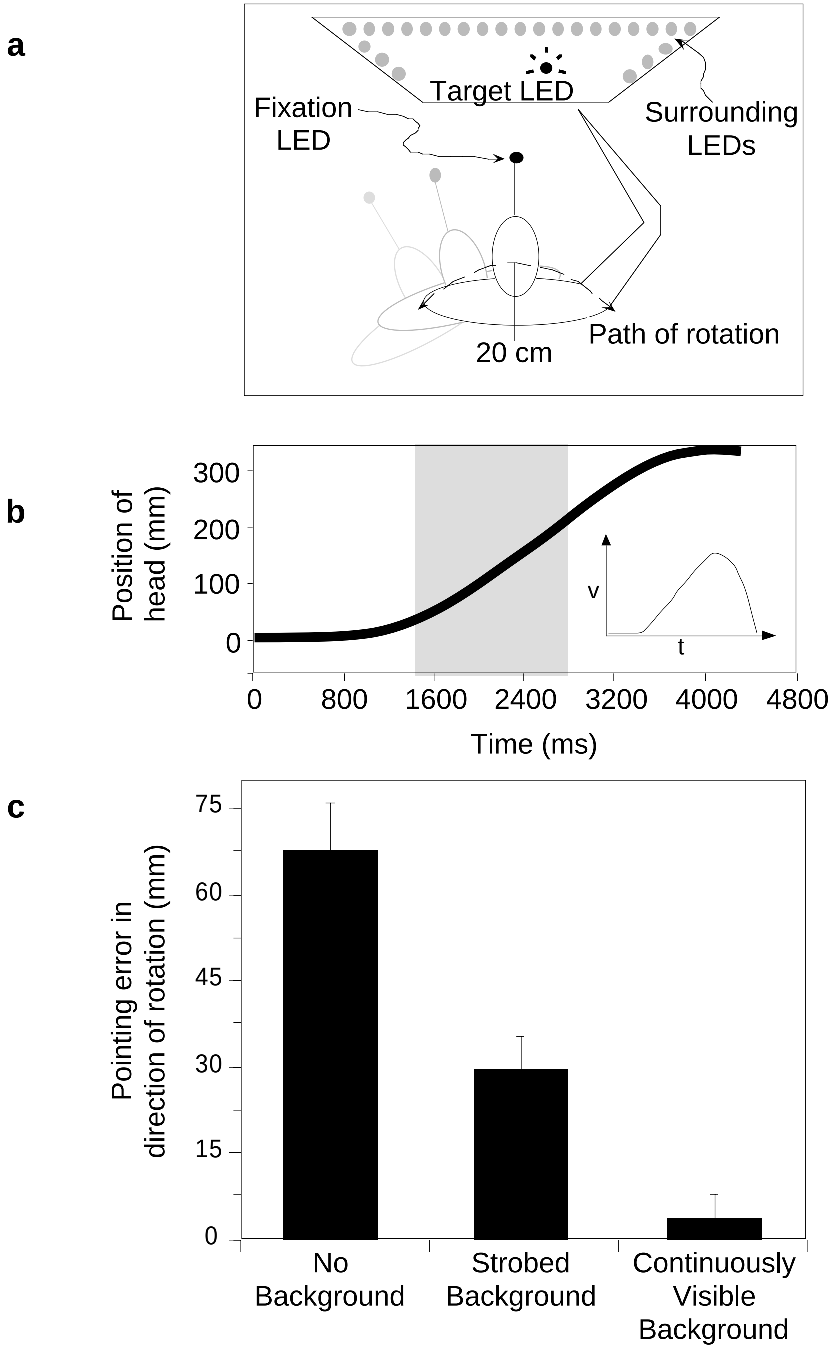
Supplemental Figure 6:



Supplemental Figure 6
Whitney, et al., 2003

Figure 6.S. Error in the trajectory of reaching movements to targets that remained visible throughout the reach for subjects DAW (**a**), DVW (**b**), and the average of three subjects (**c**). Positive values on the ordinate indicate that the hand deviated in the direction of visual motion. Consistent with previous studies[8], when the target remained visible there was a transient influence of motion on the early part of the reaching movement. There was a significant overall effect of motion on the position of the hand for DAW ($t_{(356)} = 2.99$, $P < 0.005$), DVW ($t_{(503)} = 10.9$, $P < 0.001$), and the average of subjects DAW, DVW, and ELV ($t_{(226)} = 15.0$, $P < 0.001$). Error bars, ±1 s.e.m.

Supplemental Figure 7:

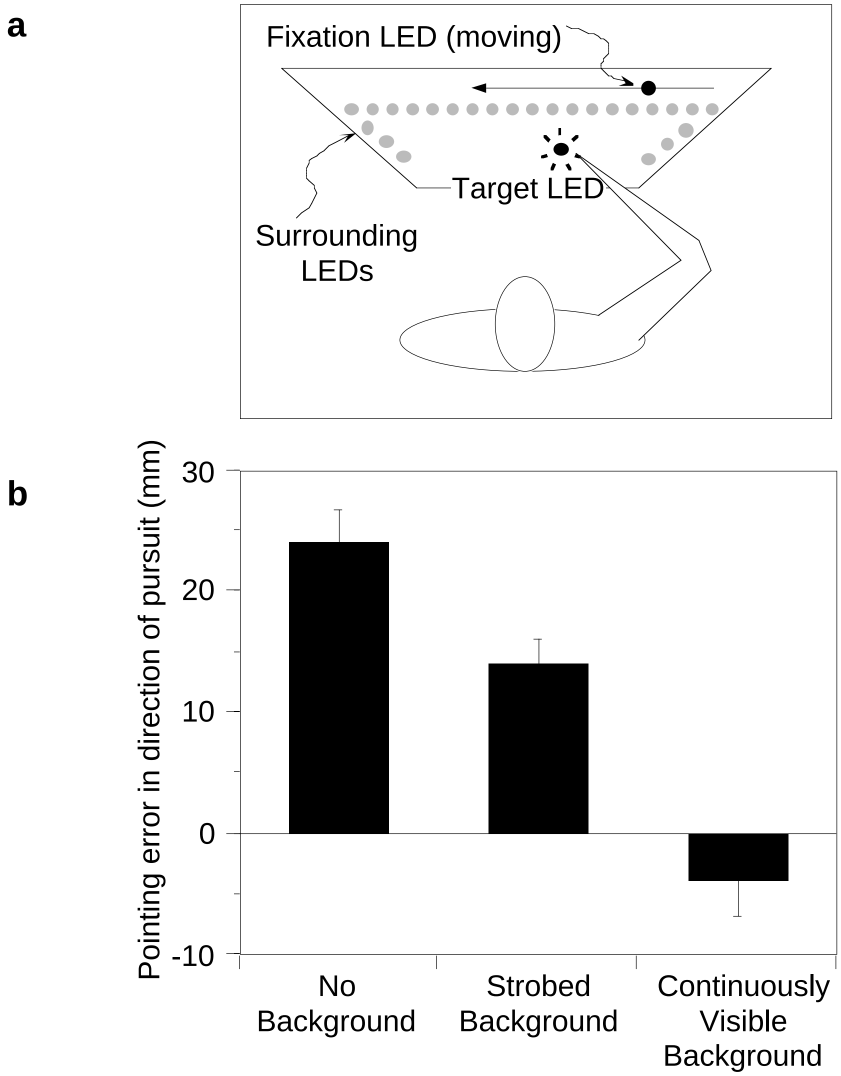


Supplemental Figure 7
Whitney, et al., 2003

Figure 7.S. Accuracy of pointing movements during passive rotation depends on the availability of visual motion signals. **a.** The experimental setup. Observers pointed to the remembered location of a ~100 ms stationary target LED while they rotated either leftward or rightward (average head velocity during the reach was ~15 cm/s; the subject's head was 20 cm from the axis of rotation; see Methods). Subjects were stationary when the target LED was presented and then passively rotated. The initial orientation of the subject was a random value on each trial between 0º (straight ahead with respect to the stimuli) and 45º (for example, 45º to the left before rotating rightward). During their rotation, at a randomly determined time within a ~1.4 s window, subjects were instructed to point to the remembered location of the LED. There were three conditions in the experiment. In the first, there was nothing visible except the target LED (no background visual cues). In the second condition there were 25 surrounding LEDs that were presented intermittently (~4 Hz), providing static position cues only (the equally spaced background LEDs formed three sides of an imaginary rectangle, 32 x 60 cm). In the third condition, the 25 background LEDs were continuously visible (the only condition in which visual motion cues were available). **b.** The average trajectory and velocity (inset) of the subject's head (measured at the bridge of the nose) during a sample experimental session (only one direction of rotation is shown). The shaded area shows the time during which the reach could be executed. **c.** The accuracy of the hand's endpoint position is graphed for each of the three conditions (calculated as signed constant error, the mean error in the endpoint of the reaching movements within each condition; positive errors indicate that pointing movements deviated in the direction of rotation—overshot the target). Consistent with previous studies[9,10], subjects tended to underestimate the magnitude of their rotation when reaching in complete darkness, resulting in pointing movements that were shifted in the

direction of their body's rotation (e.g., when subjects rotated rightward, they pointed to the right of the actual target's position). However, the accuracy of the pointing movements was greatly improved when there was background visual motion (i.e., when the background LEDs were continuously visible) compared to the condition in which no background was visible ($t_{(132)} = 6.4$, $P < 0.001$) and the condition in which the background LEDs were intermittently visible ($t_{(136)} = 4.4$, $P < 0.001$). A visual illusion, such as the flash-lag[11] or MacKay effect[12], is not responsible for the results here because observers were stationary when the target was presented (and illusions such as these only occur when a flashed object is presented while there is a moving reference visible). In a control experiment, we confirmed that the results are also not due to an error in perceived eccentricity of the target LEDs. When subjects faced ~30-45º to the right or left of the LED stimuli and were stationary (rather than rotating) throughout the trial, there was no difference in pointing movements in the three conditions. The improved accuracy in the reaching movements with a continuously visible background is therefore not likely to be due to an idiosyncratic visual illusion, but, rather, due to the addition of background visual motion. Error bars, ±1 s.e.m.

<u>Supplemental Figure 8:</u>



Supplemental Figure 8
Whitney, et al., 2003

Figure 8.S. Accuracy of pointing movements during smooth pursuit eye movements depends on the availability of visual motion signals. **a**. The experimental setup was similar to that described in Fig. 6S, except that subjects were stationary at all times. Observers pointed to the remembered location of a ~100 ms target LED (at ~40 cm distance) while they tracked a moving LED with their eyes (either leftward or rightward). At the beginning of the trial, subjects

fixated a stationary LED, during which the target LED was presented. After 500-1000 ms, the fixation point began to move either leftward or rightward (~16 cm s^{-1}). Subjects pursued the fixation point with their eyes. At a randomly determined time (between 500-1500 ms after initiation of the eye movement), subjects were instructed to point to the remembered location of the target LED. There were three conditions in the experiment. In the first, there was nothing visible except the target and fixation LEDs (no background visual cues). In the second condition there were 25 surrounding LEDs that were presented intermittently (static position cues only, ~4 Hz). In the third condition, the 25 background LEDs were continuously visible (the only condition in which visual motion cues were available). **b**. The accuracy of the hand's endpoint position is graphed for each of the three conditions (calculated as signed constant error, the mean error in the endpoint of the reaching movements within each condition; positive errors indicate that pointing movements deviated in the direction of the eye movement—overshot the target). Consistent with previous research[13,14], subjects tended to underestimate the magnitude of their pursuit eye movement when pointing in complete darkness, resulting in endpoints that were shifted in the direction of their eye movement (e.g., when subjects tracked a rightward moving fixation, they pointed to the right of the actual target's position). The accuracy of the pointing movements was greatly improved when there was background visual motion (i.e., when the background LEDs were continuously visible) compared to the condition in which no background was visible ($t_{(198)} = 9.96$, $P < 0.001$) and the condition in which the background LEDs were intermittently visible ($t_{(198)} = 7.1$, $P < 0.001$). A visual illusion, such as the flash-lag effect, is not responsible for the results, as the eye and scene were stationary when the target was presented. In a control experiment, we confirmed that the availability of visual cues before the eye movement begins also does not contribute to the improvement; when the 25 surrounding LEDs were visible before the eye movement began (providing a static reference and position cues) and then turned off at the initiation of the eye movement, pointing movements still deviated in the direction of pursuit. Consistent with previous studies, target positions were updated even though only the eye moved[5,7]. Moreover, the results show that visual motion helps update target positions, improving the accuracy of the reaching movement. Error bars, ±1 s.e.m.

References

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