Supplemental Figures and Legends

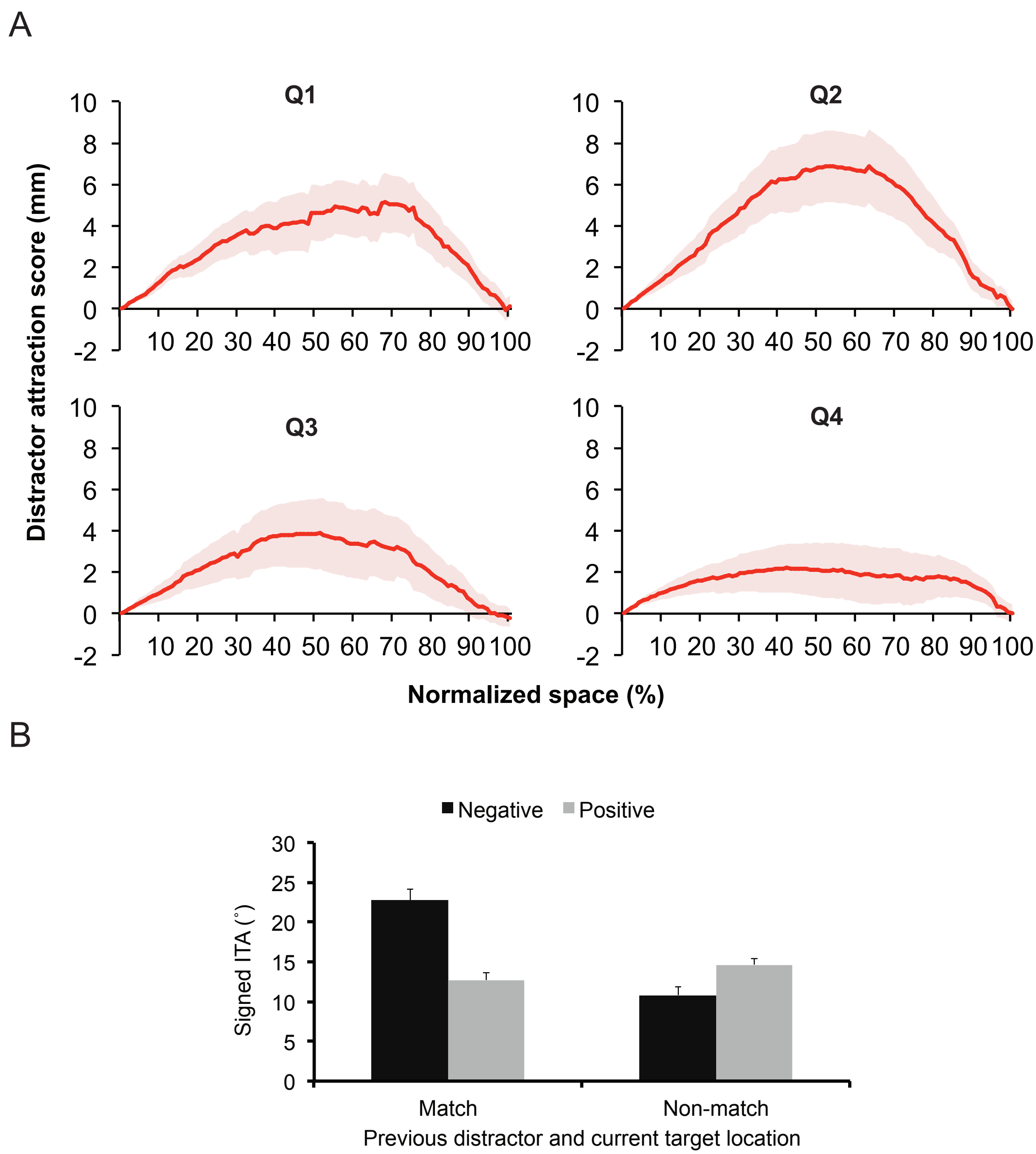

Figure S1. Linked to Figure 1 of the primary manuscript. A) Continuous distractor attraction scores for each of four initiation latency quartiles. Distractor attraction scores are reduced for movements at longer initiation latency quartiles. Analysis of attraction scores from the fastest two quartiles compared to the slowest two showed that distractor attraction scores were greater in the faster quartiles from 46% through 80% of the movement. This pattern is consistent with previous eye movement research [S1] in which distractor interference is reduced when eye movement initiation latency is longer. B) An analysis of negative priming effects [S2]. We examined whether there was greater distractor interference when the target location matched the previous trial's distractor location. Because previous research has suggested that movements deviated away from a location indicate suppression of that location [S3,S4], we also examined cases where the previous trial indicated strong inhibition because the movement was deviated away from the distractor location. Since signed ITA captures the direction of movement towards or away from a particular location, this analysis examines only consecutive distractor present trials. We conducted a 2x2 ANOVA with factors of previous ITA direction (positive vs. negative) and current target location (match or non-match to previous distractor location). Critically, we found a significant interaction between these two factors, $F(1,16) = 83.6$, $p < .001$. Simple main effects analyses revealed that when the distractor location from the previous trial became the target location for the current trial, signed ITA was greater when the previous trial's ITA direction was negative (22.7˚) than when it was positive (12.7˚), $F(1,16) = 73.6$, $p < .001$. Thus, reaching to a target location that was previously a distractor location is much more difficult when the participant exhibited strong inhibition of that distractor location during the movement on the previous trial, consistent with negative priming [S2]. On the other hand, movements to a target location that did not match the distractor location from the previous trial exhibited reduced signed ITA when the previous trial's trajectory was negative (10.8˚) compared to when it was positive (14.6˚), $F(1,16) = 10.7$, $p < .01$. Again, this is consistent with the idea that there is residual inhibition of the previous trial's distractor location when the movement was directed away from it. In this case, where the previously inhibited distractor location is again a non-target on the current trial, residual inhibition of that non-target location makes it easier to reach the target location. Together, these results provide strong evidence that movement deviated away from the salient distractor location is strongly linked with inhibition of that location that results in negative priming effects, consistent with previous models of goal-directed action [S5]. All error bars reflect S.E.M.

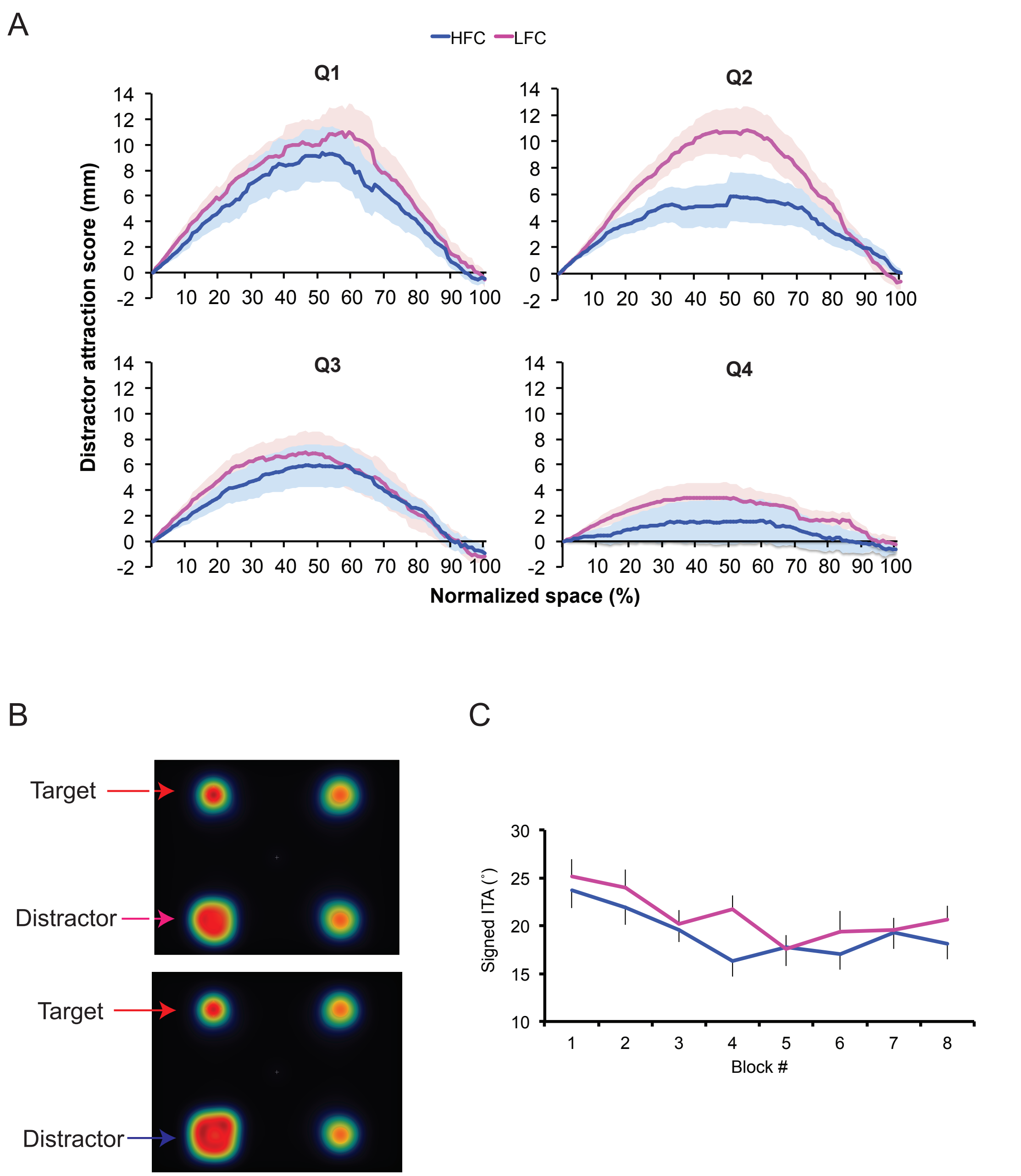

Figure S2. Linked to Figure 2 of the primary manuscript. A) Continuous distractor attraction scores for each of four initiation latency quartiles for both HFC (blue) and LFC (pink) distractors. As movements get slower, distractor attraction is reduced, as in Experiment 1; however, the difference in attraction scores between HFC and LFC trials is not limited only to slower responses. B) Saliency maps calculated according to the model proposed by Itti et al. [S6] in which bottom-up salience is calculated over an entire scene. In both figures, the target (a diamond) is at the upper left location, and the distractor is at the lower left location. The LFC (pink) distractor display is on the top, and the HFC (blue) distractor display is on the bottom. Each pixel within the figure was assigned a value reflecting the strength of saliency at that signal according to the model, with all numbers normalized to a maximum of 1. To assess the salience of each distractor type, we calculated the number of pixels in a cluster surrounding the distractor location where each pixel exceeded a threshold value of .1 in the saliency map (10% of the maximum value of 1). The cluster was greater for the HFC distractor (101,014 pixels, 7.7% of the total display) than for the LFC distractor (85,830 pixels, 6.6% of the total display). Furthermore, the sum of the values within the HFC distractor cluster (53,892) was 33.6% greater than the sum of the values within the LFC distractor (40,346). Together, these data indicate that the HFC distractor exhibited greater salience than the LFC distractor according to the Itti et al. model. Saliency maps were calculated using screenshots from Experiment 2 submitted to code generated by Jonathan Harel (A Saliency Implementation in MATLAB: http://www.klab.caltech.edu/~harel/share/gbvs.php). C) Signed ITA for HFC and LFC distractor trials separated by block. There was a main effect of block, $F(7,112) = 5.2$, $p < .001$, best explained by a linear trend in which distractor interference is reduced over the course of the task, $F(1,16) = 15.0$, $p < .01$. However, there was no interaction between block and distractor type, $F(7,112) = 1.1$, *n.s*. Thus, reduced distractor interference on HFC relative to LFC trials was not dependent on long-term learning. All error bars reflect S.E.M.

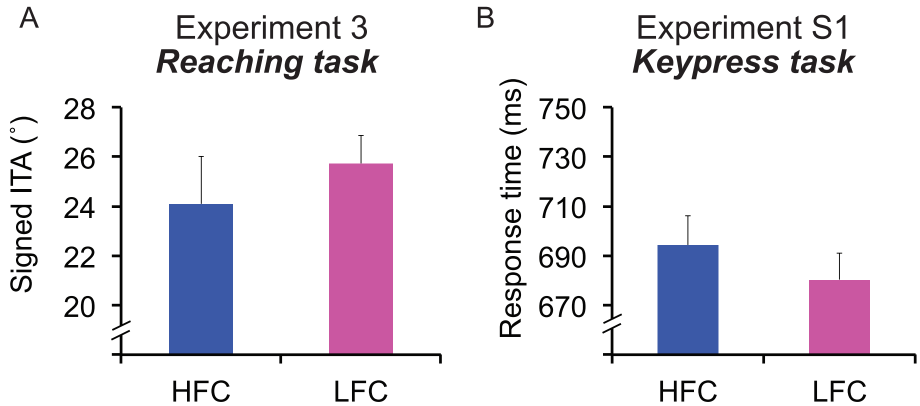

Figure S3. Linked to Figure 3 of the primary manuscript. A) Signed ITA sorted by distractor type (HFC vs. LFC) for Experiment 3. The pattern of results from Experiment 3 replicates Experiment 2 (see Figure 2). Although the comparison of ITA for HFC and LFC trials failed to reach statistical significance in Experiment 3, $t(11) = 1.18$, *n.s.*, the magnitude of the effect was similar to Experiment 2 (1.64° greater for LFC than HFC in Experiment 3, compared to 1.69° greater for LFC than HFC in Experiment 2). Furthermore, a mixed ANOVA combining signed ITA data from Experiments 2 and 3 with distractor type as a within-subject variable and experiment as a between-subject variable revealed a main effect of distractor type, $F(1,27) = 6.67$, $p < .05$, but no interaction between experiments, $F(1,27) = 0.002$, $p = .97$. As in Experiment 2, the difference in trajectory deviation between HFC and LFC trials in Experiment 3 cannot be explained by slower initiation latencies on HFC trials, as initiation latencies were not different between the two (HFC: 417 ms, LFC: 420 ms), $t(11) = 1.3$, *n.s.* B) Results from Experiment S1. A possible alternative explanation for the dissociation in Experiment 3 is that the goal-directed action task may have required a more precise localization of the target relative to the orientation discrimination in the keypress task. In other words, the divergent results might be attributable to task differences rather than differences in how salience affects performance depending on the mode of response. To address this possibility, we conducted an additional experiment in which observers were required to press a key to indicate the location of the target. Otherwise, the experiment was nearly identical to the keypress task in Experiment 3. The data closely mirror the keypress results from Experiment 3. Response times were longer on HFC trials (694 ms) compared to LFC trials (680 ms), $t(11) = 2.69$, $p < .05$. This result indicates greater interference from the more perceptually salient HFC distractor, in contrast to the results from the goal-directed action tasks in Experiments 2 and 3 showing reduced interference from the HFC distractor relative to the LFC distractor. Error rates (not pictured) showed the same pattern; errors were marginally more frequent for HFC trials (5.3%) than LFC trials (4.2%), although this difference only approached significance, $t(11) = 1.97$ $p = .07$. Full results can be found in Table S2. All error bars reflect S.E.M.

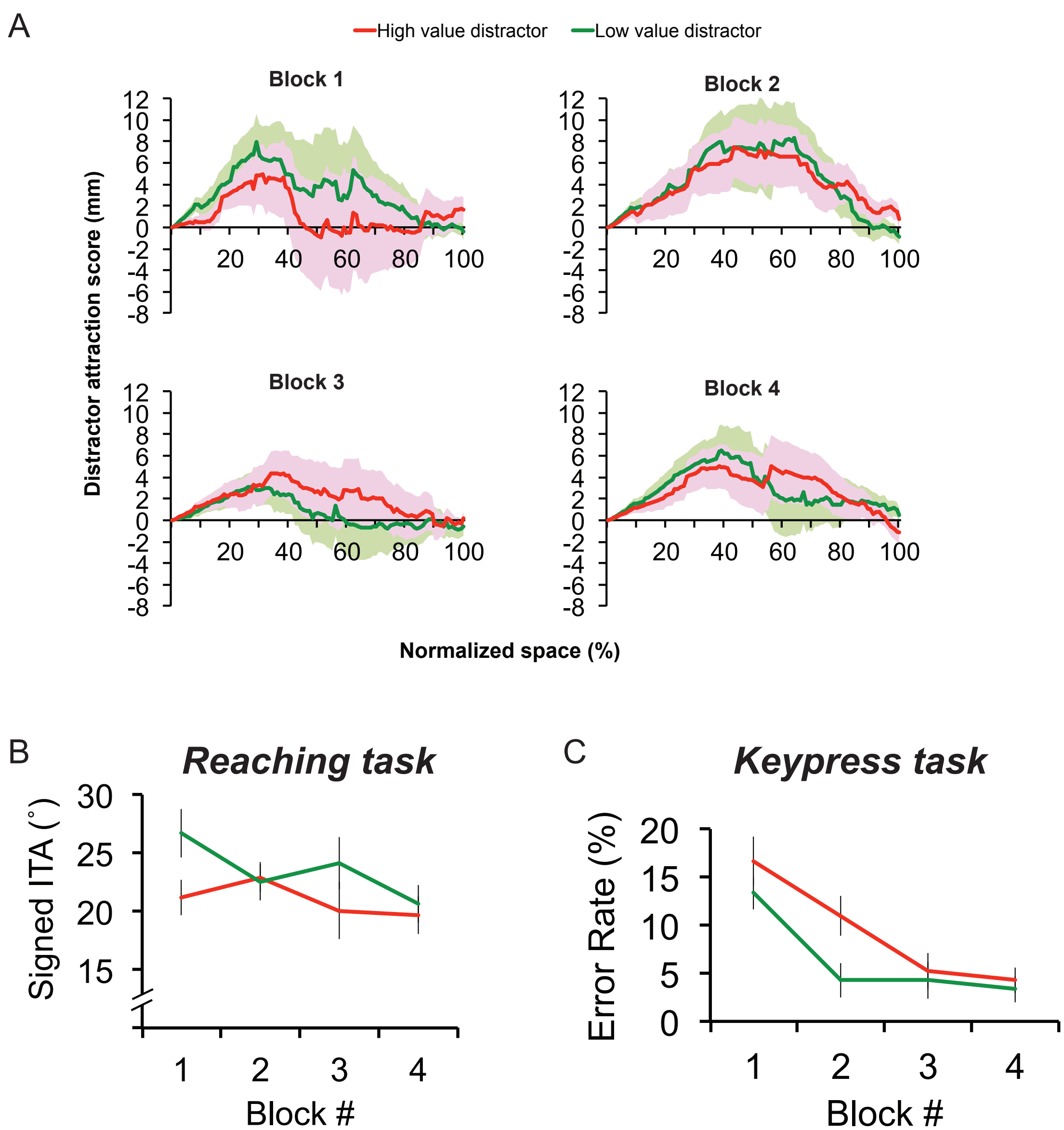

Figure S4. Linked to Figure 4 of the primary manuscript. A) Distractor attraction scores from Experiment 4 separated by block, B) signed ITA from Experiment 4 separated by block, and C) error rate in Experiment 5 separated by block. Previous studies of value-driven capture by physically salient stimuli indicate that the effect of value is diminished over the course of the test phase, as the reward associations are no longer reinforced [S7]. Thus, here we conduct a more thorough analysis of the data in Experiments 4 and 5 as a function of block number. Although the interactions between block and distractor type failed to reach significance for these analyses, we present the data here for the sake of completeness. All error bars reflect S.E.M.

Table S1

Descriptive statistics for reach movement data from Experiments 1-4

		Inititaion latency (ms)	Movement time (ms)	Error rate (%)
Experiment 1				
	Distractor absent	340 ± 12 ms	406 ± 12 ms	3.9 ± 0.7 %
	Distractor present	345 ± 12 ms	417 ± 12 ms	6.1 ± 0.9%
Experiment 2				
	Distractor absent	406 ± 13 ms	433 ± 8 ms	8.7 ± 1.4 %
	HFC distractor	407 ± 13 ms	439 ± 8 ms	11.3 ± 1.4%
	LFC distractor	409 ± 13 ms	441 ± 8 ms	12.0 ± 1.6%
Experiment 3				
	Distractor absent	417 ± 13 ms	404 ± 9 ms	9.0 ± 2.2 %
	HFC distractor	417 ± 14 ms	413 ± 9 ms	12.2 ± 2.7%
	LFC distractor	420 ± 14 ms	414 ± 11 ms	11.4 ± 2.9%
Experiment 4				
	Distractor absent	431 ± 16 ms	467 ± 11 ms	4.3 ± 1.0 %
	High reward distractor	438 ± 16 ms	492 ± 11 ms	9.3 ± 1.6%
	Low reward distractor	441 ± 16 ms	489 ± 10 ms	10.2 ± 1.5%

Note: Error terms reflect standard error of the mean (S.E.M.)

Table S2

Descriptive statistics for keypress data from Experiments 3 and 5

		Response time (ms)	Error Rate (%)
Experiment 3			
	Distractor absent	938 ± 32 ms	22.0 ± 2.3 %
	HFC distractor	963 ± 33 ms	27.3 ± 3.0%
	LFC distractor	950 ± 32 ms	26.0 ± 3.0%
Experiment 5			
	Distractor absent	918 ± 21 ms	7.0 ± 1.0 %
	High reward distractor	938 ± 20 ms	9.3 ± 1.3%
	Low reward distractor	933 ± 23 ms	6.3 ± 0.9%
Experiment S1			
	Distractor absent	667 ± 14 ms	3.2 ± 0.6 %
	HFC distractor	694 ± 12 ms	5.3 ± 0.8%
	LFC distractor	680 ± 11 ms	4.2 ± 0.7%

Note: Error terms reflect S.E.M.

Supplemental Experimental Procedures

Recording and data analysis methods were largely adapted from Ref. S8.

Participants. Brown University undergraduate students and community members (Experiment 1: 5 Male, 11 female, mean age = 19.4 years; Experiment 2: 8 Male, 11 female, mean age = 21.95 years; Experiment 3: 5 Male, 9 female, mean age = 21.1 years; Experiment 4: 9 Male, 11 female, mean age = 20.7 years; Experiment 5: 6 Male, 8 female, mean age = 24.6 years, Experiment S1: 2 male, 10 female, mean age = 19.9 years) participated for course credit or monetary compensation. All participants were right handed with normal or corrected-to-normal visual acuity and normal color vision. The protocol was approved by the Brown University Institutional Review Board.

Apparatus. Stimuli were projected from behind a Plexiglas display that was arranged upright on a table perpendicular to the observer's line of vision, facing the seated observer at a distance of approximately 48 cm. A motion tracking marker was secured with a Velcro strap near the tip of each observer's right index finger. The observer's index finger was rested on a Styrofoam block placed in front of them on the table, located 27 cm from the screen along the z-dimension (i.e., the axis that is bounded by the observer and the display). The finger was aligned with the bottom of the display along the y-dimension (i.e., the axis that is bounded by the top and bottom of the display), and the horizontal midline of the display along the x-dimension (i.e., the axis that is bounded by the left and right sides of the display).

Data Analysis. When the participant's finger came within approximately 1.3 cm of the display on the z-dimension and simultaneously within approximately 2 cm of the center of the target on the x and y dimensions within the one-second time limit, a response was considered correct. If this threshold was passed for a non-target object, or the participant did not cross any reaching threshold during the time limit, the trial was counted as incorrect.

Hand movement data were analyzed offline using custom MATLAB (Mathworks) software. Three-dimensional speed scalars were created for each trial using a differentiation procedure in MATLAB. These scalars were then submitted to a Butterworth filter (2nd order, 10 Hz high cutoff). *Movement onset* was calculated as the first time point on each trial after stimulus onset at which hand movement resultant speed exceeded 25.4 cm/s. *Resultant speed* was calculated as the three-dimensional distance traveled (i.e., the square root of the sum of the squared distance traveled along the x, y, and z axes) at each sample divided by the time elapsed since the previous sample. *Movement offset* was defined as the first subsequent measurement on each trial when resultant speed decreased to below 25.4 cm/s. Each individual trial was visually inspected [S8,S9]; for trials where the default threshold clearly missed part of the movement or included substantial movement back to the starting point, thresholds were adjusted manually to more appropriate levels for that trial (Exp. 1: 2% of all trials, Exp. 2: 2%, Exp. 3: 3.9%, Exp. 4: 2.8%). Additionally, trials in which samples were dropped from recording during movement due to technical issues with tracking equipment were eliminated from analysis (Exp. 1: 1.5% of all trials, Exp. 2: 0.1%, Exp. 3: 0.4%, Exp. 4: 0.08%). Two participants each were removed from Experiment 2 and Experiment 3 analyses because they were unable to respond accurately on at least 50% of all trials.

To determine whether movements were pulled towards or away from the location of the salient distractor relative to baseline movements from distractor absent trials, we computed a *distractor attraction score*. First, we resampled each movement to 101 points equally spaced in space [S8,S10]. Next, we calculated the distance at each point between distractor present trials and distractor absent trials for each of twelve possible combinations of target and distractor location. In Fig. 2A, this would represent the difference between the black and red line at each sample in the movement. Positive numbers reflected that a line connecting that point on the trajectory to the beginning of the movement was directed towards the distractor relative to a line connecting the beginning and endpoints of the movement, and that the polar angle of the movement was also directed towards the distractor location relative to the angle at the same point on a distractor absent trial. If neither of those conditions was met, the number was instead negative. This is consistent with previous studies measuring activation and suppression through the direction of deviation in hand movement trajectories [S3,S4]. Finally, we calculated the mean of all twelve of these differences for each subject to create distractor attraction scores for each participant at each point of the movement. Distractor attraction scores reflect how far hand movements were pulled in mm towards the distractor location on distractor present trials.

We used a cluster-based analysis to determine when during the movement the distractor disrupted trajectories [S11]. We calculated the t-statistic for the distractor attraction score at each time point, then searched for the largest consecutive cluster of time points at which the t-statistic was above threshold and calculated the sum of t-values within that cluster (threshold set for each experiment as the t-value for the degrees of freedom of that experiment at $\alpha = .05$.). We then randomly permuted the order of t-statistic values 100,000 times and performed the same cluster analysis on each permutation to get a distribution of possible cluster sizes against which to calculate p value for the observed cluster size. If the observed cluster size was significant with $p < .05$, we reported the start and end points of the cluster as the points of the movement that were affected by distractor presence.

Trajectories for calculating initial trajectory angle (ITA) were measured in two-dimensional XY space by calculating a line from the start to the end point of the movement, and measuring the polar angle between that line and the actual movement at a point closest to 20% of the time through completion of the movement [S12]. In Experiments 2-4, we used a signed ITA measure by denoting the ITA measure on each trial as positive if it was closer in space to the location of the singleton distractor relative to a line connecting the start and endpoints of the movement, and negative if this condition was not met.

In some analyses for the supplemental materials, we divided all trials into four quartiles based on initiation latency, from shortest to longest. Quartiles were calculated separately for each of the four target locations to ensure that differences in reach trajectory in different initiation latency quartiles were not attributable to differences in the distribution of target and distractor locations within a particular quartile.

Stimuli. All stimuli appeared on a black background. A white fixation cross appeared at the center of the screen at the beginning of each trial, measuring 0.5 cm^2 from edge to edge. Four objects appeared on the screen during each trial. Each object was either a circle or a diamond, each measuring 2 cm from edge to edge. On each trial, one of the four objects was designated as the target (randomly selected for each trial to be a circle or diamond). The remaining three objects appeared in the remaining shape type, such that the target shape was a singleton along the shape dimension (e.g., a circle among diamonds). On each trial, the target and two non-target objects were rendered in green. The remaining object was colored red on a randomly selected 50% of all trials (a color singleton distractor), and green on the remaining trials. Therefore, a salient color distractor was present on 50% of all trials, and never coincided with the target. The four objects were equally spaced at 15.7 cm apart from center to center, and placed at 1:30, 4:30, 7:30 and 10:30 on an imaginary circle surrounding fixation. The distance between each item's center and the center of fixation was 10.9 cm (Fig. 1A).

In Experiments 2 and 3, we increased the overall display size to increase our power to detect more subtle difference in reach trajectory. As a result, the size of the fixation cross was 0.7 cm^2 from edge to edge, the size of the objects was 2.8 cm from edge to edge, the spacing between each item was 22 cm apart from center to center, and the distance between each item's center and the center of fixation was 15.3 cm (Fig. 2A). Colors were also different from Experiment 1, in order to provide a difference in feature-contrast between distractors. The target and two non-target objects were rendered in red. The remaining object was colored pink on a randomly selected 25% of all trials, blue on another 25% of all trials, and red on the remaining trials. In the keypress task of Experiment 3, each shape contained a white line measuring 1.4 cm by 0.1 cm. The line inside the target was oriented vertically on a randomly selected half of all trials and horizontally on the other half. For distractor present trials, the same ratio applied to the line inside the salient distractor. The line was randomly selected to be either horizontal or vertical with equal probability for the remaining non-target shapes for each trial. All colors were matched for luminance using photometer calibration.

Experiments 4 and 5 largely used the same stimuli. However, objects in the training phase consisted only of circles. In addition, during the training phase, each trial included a single target randomly selected to be colored either red or green with equal probability. The remaining three objects were randomly selected to be colored blue, pink, yellow, or orange, with no two objects colored the same on any trial. All colors were matched for luminance with photometer calibration. There were no lines inside each object in Experiment 4, since only reach movement responses were required. For Experiment 5, a line inside the target was randomly assigned to be either horizontal or vertical; lines inside all other objects were randomly assigned to be diagonally aligned either rightward or leftward to replicate Ref. S7.

Stimuli in Experiment S1 were identical to those used in Experiments 2 and 3. There were no lines presented inside each object, as the only information required for a keypress response was the location of the target.

Procedure.

Experiment 1. Nine-point hand calibration occurred at the beginning of the session. During the experiment, participants were instructed to keep their finger in the starting position until the target stimuli appeared, and to touch the unique shape on every trial. Each trial began with the presentation of a fixation cross for either 500 or 750 ms (randomly selected for each trial). To discourage hand movements from occurring before the target stimuli appeared, if the participant moved their finger during the presentation of the fixation cross, they had to wait for an additional 500-750 ms after returning their finger to the starting position. Following fixation, the colored shapes appeared. If the participant did not touch one of the four shapes within 1 second, the trial was counted as incorrect, and a tone was played to indicate to the participant that time ran out. The display remained on the screen for an additional 200 ms after the participant's response to encourage participants to rest briefly on the target. This resulted in more consistent deceleration at the end of reach movements, allowing us to effectively use maximum and minimum speed thresholds to analyze movement trajectories. Following every trial, participants were given an auditory feedback tone to indicate whether their response was accurate (high pitch beep), or inaccurate (low pitch beep). There was a 1 second intertrial interval.

The experiment began with 20 practice trials, followed by 8 blocks of 100 trials each. Participants were given an opportunity to rest between each block. Each session lasted approximately one hour.

Experiment 2. The procedure was similar to Experiment 1, except that there were two possible singleton distractor colors. These colors were defined as the *high feature-contrast (HFC) distractor* (blue, .539 away from the red used for all other items in CIE color space) and *low feature-contrast (LFC) distractor* (pink, .229 away from the red used for all other items in CIE color space; Fig. 2A). To further ensure that the HFC distractor exhibited greater perceptual salience, we calculated saliency maps from screenshots of displays from Experiment 2 (1280 x 1024 pixels; see Fig. S2B).

Experiment 3. The procedure was similar to Experiment 2, except that each participant completed two phases of the Experiment. One phase was identical to Experiment 2, with the exception that only 400 total trials were conducted after practice. The other phase required keypress responses rather than reaching responses. The task for this phase was similar to Experiment 2, except that participants were instructed to respond by indicating whether the line inside the target shape was oriented horizontally (by pressing the "z" key) or vertically (by pressing the "m" key). The response deadline for this task was 1.5 seconds, to encourage rapid responses as in the reaching task. Participants completed 400 total trials of this phase after practice as well. The order of these two phases was counterbalanced across subjects.

Experiment 4. The procedure for Experiments 4 and 5 was largely modeled after Ref. S7. There were two phases in Experiment 4. During the initial training phase, participants received 50 practice trials followed by 4 blocks of 60 trials each. On each trial, participants had to reach to the red or green target (one or the other was present on every trial). One color was assigned for each participant as the "high value" color, meaning that correct responses would result in a 10¢ reward 80% of the time, and a 2¢ reward 20% of the time. The other color was "low value," with a 2¢ payout 80% of the time and a 10¢ payout 20% of the time. After each response, participants were presented with a display for 1.5 seconds that indicated both how much they earned for that response, and how much they had earned total thus far in the experiment.

Immediately following the training phase, participants conducted the test phase. In the test phase, participants performed a task very similar to Experiments 1-3. That is, they reached to the unique shape on each trial, and a randomly selected 50% of all trials, a singleton color distractor was present. When a color distractor was present, it was equally likely to be either red or green. All other items were colored gray. There were 20 practice trials, during which no color singleton distractor appeared. Participants then completed 4 blocks of 60 trials each. There was no reward offered for correct answers during the test phase.

Experiment 5. Experiment 4 was identical to Experiment 5, except that observers had to respond to targets by indicating the orientation of a line inside the target by pressing “z” for a horizontal line or “m” for a vertical line.

Experiment S1. Experiment S1 was similar to the keypress task in Experiment 3. Participants searched for a unique target, and color singleton distractors appeared on some trials either in pink (LFC) or blue (HFC). However, instead of pressing a key to indicate the orientation of a line inside the target, observers pressed one of four keys (“a”, “z”, “k”, and “m”) to indicate the location of the target shape (upper left, lower left, upper right, and lower right respectively). Participants completed 20 practice trials, followed by 6 blocks of 100 trials each.

Supplemental References

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