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Hand Movements Deviate Toward Distracters in the Absence of Response Competition

STEVE W. C. CHANG
RICHARD A. ABRAMS
Department of Psychology
Washington University

ABSTRACT. In a series of experiments, participants reached to targets in the presence of visual distracters that were either adjacent to the target or located along the reach path. The reaching movements were affected by the presence of the distracters, with the movement paths deviating toward the distracters. Those deviations were observed under two different conditions: (a) one in which the distracter could potentially have been a movement target; and (b) another in which the distracter never was a possible target. Because the movement was affected by the distracter in both situations, the results suggested that response competition is not necessary for distracter-induced reach-path deviations. Instead, the authors propose that attention to a distracter is sufficient to affect the to-target movement. The movement deviations may reveal an effective mechanism for coping with stimulus-rich environments.

Key words: attention, eye-hand coordination, movement trajectory, reaching

PEOPLE AND OTHER ANIMALS must produce movements that allow them to interact appropriately with objects in their environment so that they can survive. Often, the desired object, for example, a ripe fruit in a tree, is embedded in a context in which there are many competing undesired objects, such as unripe fruits, tree branches, leaves, and so on. A primary goal of the actor is typically to avoid the undesired objects and instead to act selectively toward or to interact with the desired object. Psychologists who are interested in the mechanisms underlying the control of such behaviors have studied those processes by having people reach for, point to, and grasp objects in laboratory experiments (e.g., Castiello, 1996;

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Address correspondence to Richard A. Abrams, Department of Psychology, Washington University, St. Louis, MO 63130-4899; RAbrams@WUSTL.edu (e-mail).

Keulen, Adam, Fischer, Kuipers, & Jolles, 2002; Pratt & Abrams, 1994; Sailer, Eggert, Ditterich, & Straube, 2002; Tipper, Lortie, & Baylis, 1992). In the present article, we report experiments that continue that tradition. Our interest is in the trajectories of movements that people make while they reach to touch target objects in the presence of distracting nontarget objects. It is worth noting that much can also be learned about the underlying mechanisms by examining temporal aspects of the movements or their landing points. Such is the approach taken by a number of researchers (e.g., Fischer & Adam, 2001; Pratt & Abrams). In the present study, we were specifically concerned with features of the movement trajectories.

Research to date on that topic has been characterized by a variety of different types of tasks that have produced results that sometimes seem to be at odds with one another. For example, Howard and Tipper (1997) had participants reach for and lift small objects on the surface in front of them. They showed that actors avoided nontarget distracters by causing their to-target hand movements to veer away from the distracters. Howard and Tipper proposed that movements are biased away from distracters by an inhibitory attentional mechanism that suppresses the tendency to move toward the distracter. Tresilian (1998) reported results that suggest instead that movements might veer away from a distracter merely because of a desire on the actor's part to avoid colliding with an obstruction. Furthermore, Welsh, Elliott, and Weeks (1999) found that aiming movements with a computer mouse veered toward, not away from, distracting stimuli. They suggested that response competition might occur between targets and distracters when the distracters are also potential targets. In support of that suggestion, Cisek and Kalaska (2002) have reported brain activity consistent with an initial preparation of several potential movements before the final selection of a single movement. Researchers have also observed similar deviations toward distracters in a line-drawing task (Chieffi, Ricci, & Carlomagno, 2001).

In the present study, we focused on questions about response competition. In particular, we studied movements in which actors moved their hands to virtual and physical targets in the presence of virtual distracters that could not possibly be physically obstructing, as in Welsh et al. (1999). Such a paradigm has the virtue of realistically simulating many tasks in which people interact, either via mouse or hand (e.g., on a touch-screen), with electronic visual displays. Furthermore, the use of virtual distracters permits one to eliminate the possibility of collision with physical distracters (Tresilian, 1998). The effects of possible collisions are worthy of study in their own right, but they were not our focus in the present study. Our interest was in determining the extent to which response competition is necessary to produce movement deviations toward distracters, as has been reported by Welsh et al. Although such competition seems likely to play a role in distracter-induced movement deviations, it also seems possible that mere attention to a distracter could affect a movement even under conditions in which the distracter is not a potential target. In the present experiments, we investigated that possibility.

In Experiments 1 and 2, we sought to replicate the general pattern of the Welsh et al. (1999) experiments by using virtual distracters in a visual display as they had, but with pointing limb movements instead of mouse-cursor movements. To anticipate the results, we did indeed detect movement deviations toward the distracters. However, the distracters were also potential target locations, so it is unclear if the movement deviations were caused by response competition or by an attentional effect, or both. In Experiment 3, we attempted to distinguish between those possibilities by using distracting elements that were never potential targets. Any movement deviation caused by such distracters could not be owing to response competition, but must instead be owing to some type of attentional effect of the distracter on the to-target movement.

EXPERIMENT 1

The purpose of Experiment 1 was to examine how a virtual visual distracter influences the spatial component of a reaching movement. We began by initially presenting two potential targets for a movement. Subsequently, one of the potential targets became the actual target, and the other became a nontarget distracter. For each movement directed to the target, we examined the participants' reaching trajectories when the distracter was located spatially to the left or right of the target.

Method

Participants

Ten Washington University undergraduates who were naive to the task participated for an hour for class credits. All the participants were right-handed with normal limb functions and had normal or corrected vision.

Apparatus

An IBM-compatible PC controlled the presentation of stimuli, which were displayed on a 15-in. flat LCD panel (Viewsonic, Model VG150). White elements were presented on a black background. Some of the elements changed their colors during the experiment (see Procedure). The display panel was mounted in a wooden frame (16.5 in. wide, 14 in. deep, 3.5 in. high) under glass protection. The frame was fixed to the table in front of the participant and oriented so that the surface sloped upward away from the participant at a 25.6° incline. Each movement started at the bottom of the display panel. Targets were positioned along an imaginary circle centered on the starting location and with a radius of 7.725 in. at angular positions of 11° and 35° to both the left and right of a line extending from the starting position perpendicular to the long edge of the display monitor. Hand trajectories were monitored by a Flock of Birds (Ascension Technology Corp.) three-dimensional tracking device (sampling rate: 100 Hz). The tracked sensor was mounted on the index finger of a leather glove that the participants wore on their right hands throughout the experiment.

Procedure and Design

The participants sat in a dimly lit room in front of the table on which the display device was located. We asked them to maintain a steady posture throughout the experiment. Figure 1 shows the sequence of events on a trial. The fixation

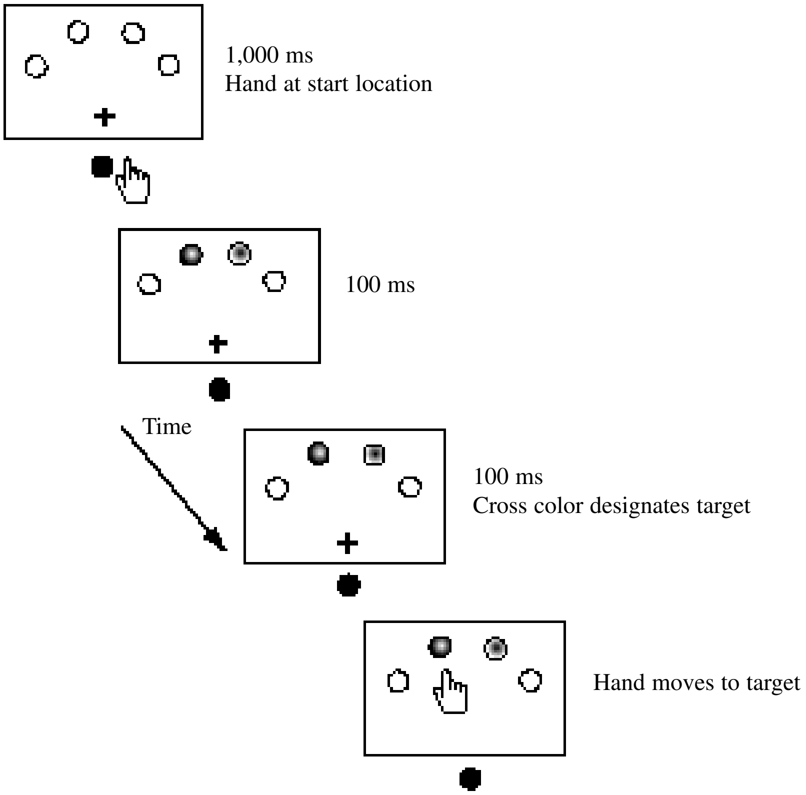

FIGURE 1. The sequence of events in Experiment 1. The dashed lines show potential target locations and were not visible in the display. Two of the four potential target locations were visible on each trial; one was colored red and the other green. The color of the fixation cross indicated which of the two was the target. See text for additional details.

cross for each trial blinked (5 Hz) and a tone was presented (200 ms, 20 Hz) until the participants positioned their right index finger on the starting location, which was situated on the glass 3.5 in. away from the fixation cross. The participants were told to maintain their gaze at the fixation cross at the beginning of each trial. The trial began 1,000 ms after the index finger rested on the starting position. At the beginning of each trial, two filled-in circles (potential targets) appeared at two of the four potential target locations (the other target locations were not visible) and remained on until the end of the trial (see Figure 1). One of the circles was green, and the other was red. After 100 ms, the fixation cross changed its color to either red or green—specifying by color the movement target for that trial. The fixation cross disappeared after another 100 ms. That was the imperative signal for the participant to move his or her fingertip as quickly as possible from the starting location to the designated target location. If the participants did not make any error (see error criteria under the heading Reaching Movement Analysis), a tone (1,000 ms, 300 Hz) confirmed a correct reach and instructed them to return their hands to the starting location for the next trial. If the participants made an error, then an error tone was presented and an informative message was displayed (for error types, also see Reaching Movement Analysis).

We included 10 experimental blocks of 48 trials each. The target appeared equally often at each of the four locations, and for each target location, the distracter was equally likely to be at each of the other three locations. The color of the potential targets, either red or green, was chosen randomly. One half of the trials used a red signal. A practice block identical to the experimental blocks was presented at the beginning of each session.

Reaching Movement Analysis

All reaching trajectories were recorded in three dimensions at a rate of 100 Hz. A reach to a target was considered acceptable if the finger landed inside a 3 in. × 3 in. × 1.5 in. volume that included the target at the center of the bottom of the space. That relatively large target window was used because the glass pane over the video display and the position of the sensor on the participant's fingertip produced a modest parallax error. If the hand traveled more than 2.5 in. in any one of the three dimensions during the time period up to 10 ms after the fixation cross was removed, then the trial was considered to have an early response error, and it was discarded. In addition, if the hand had not traveled more than 0.1 in. within 500 ms after the imperative signal, the trial was considered to have a slow start error. Trials with any of those errors were not included in any further analysis. Data with abnormal trajectories that ended in the correct location were identified at the level of raw data and discarded. Such abnormal movements constituted on average 3% of a participant's total movements.

The start of each movement was registered when the finger traveled more than 0.1 in. in any direction. The end of each movement was defined as the beginning of a run of four consecutive samples in which the position changed by less than 0.1 in. in each of the three dimensions. Positions were computed for points that were 25%, 50%, and 75% of the nominal distance between the center of the movement starting point and the movement endpoint. We analyzed only the two dimensions that corresponded to the plane of the display or movement surface. Analyses were performed for trials on which the target was one of the middle two target locations because those targets permitted the use of distracters on both the left and the right (on separate trials, see Figure 2). Trials in which the target and distracter were not adjacent were not analyzed.

Results

Figure 2 shows smoothly fitted mean movement paths for movements to each of the middle two targets separately for distracters to the left and right. All the analyses described hereinafter were conducted on the actual hand positions at points that were 25%, 50%, and 75% of the distance from the start to the target.

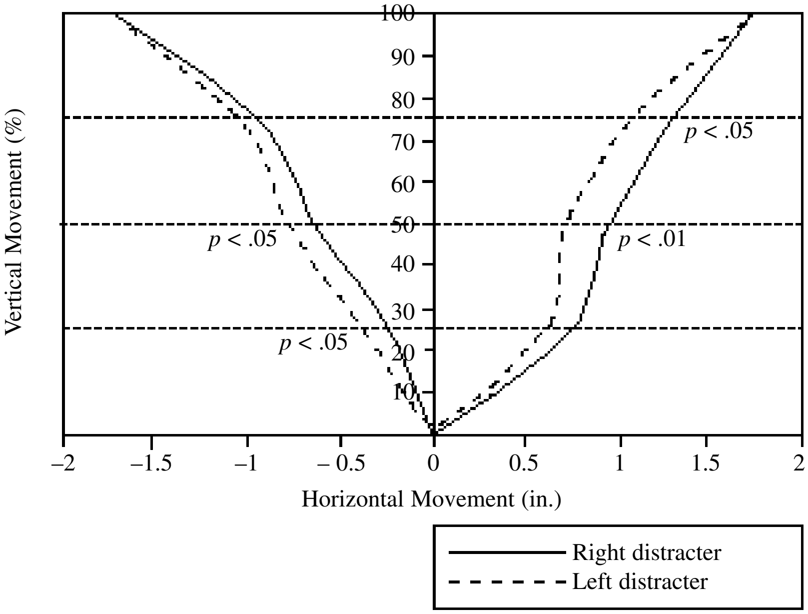

FIGURE 2. Mean movement paths from Experiment 1 to the near-left and near-right target locations, shown separately for distracters on the left and right. The *p* values show results of the *t* tests comparing distracter-left and distracter-right conditions at points corresponding to 25%, 50%, and 75% of the distance from the start to the target. All significant comparisons are shown.

Movements made to either target followed different paths depending on the location of the distracter. As one can see in Figure 2, the movements deviated toward the distracter.

The movement trajectory positions for every participant for all conditions were submitted to a 2 × 2 × 2 (Target Color × Target Location × Distracter Location) analysis of variance (ANOVA) separately for the lateral position of the hand (i.e., perpendicular to a line between the starting position and the center of the target array) at each of the 25%, 50%, and 75% distances. For the 25% and 50% analyses, the movement paths were deviated significantly toward the location of the distracter, $F(1, 9) = 6.03$, $p < .05$, and $F(1, 9) = 11.07$, $p < .01$, respectively. For the 75% of movement distance, a similar movement deviation was present, but was only marginally significant, $F(1, 9) = 4.38$, $p = .07$. As expected, there were no effects of target color: 25%, $F(1, 9) = 0.07$, $p = .79$; 50%, $F(1, 9) = 2.95$, $p = .12$; and 75%, $F(1, 9) = 1.93$, $p = .20$. There were also no significant interactions between target location and distracter location: 25%, $F(1, 9) = 0.12$, $p = .74$; 50%, $F(1, 9) = 1.50$, $p = .25$; and 75%, $F(1, 9) = 3.72$, $p = .09$, which ruled out any differential effect of visual distraction on leftward or rightward movements.

The data were further submitted to paired *t* tests to compare path differences for movements to right and left distracters for each target. Those values are shown in Figure 2 at appropriate locations within the figure: 25% left target, $t(9) = 2.30$, $p < .05$; 25% right target, $t(9) = 1.22$, $p = .24$; 50% left target, $t(9) = 2.56$, $p < .05$; 50% right target, $t(9) = 2.98$, $p < .01$; 75% left target, $t(9) = 1.46$, $p = .16$; and 75% right target, $t(9) = 2.56$, $p < .05$. Most of the tested locations (25%, 50%, and 75% for each target) showed significant differences between distracters located to the left and right of the target. For those that show significant differences, the movement paths always deviated toward the location of the distracter. For the comparisons that did not achieve statistical significance, the trend was that the deviations were always toward the distracter (see Figure 2).

We detected no movement within 500 ms of the signal on 3.5% of the trials. The participants began early (.12%) or missed the target (.29%) on only a very few trials. The overall mean reaction time (RT) in the experiment was 438 ms. The RT did not depend on the level of any of the factors, nor were there any interactions.

Discussion

In Experiment 1, movements deviated toward the location of a distracter, which was similar to the findings of Welsh et al. (1999). Because both the target and distracter were potential targets, one possible explanation is that participants partially prepared movements to both potential locations prior to target specification. The to-target movement may then have been contaminated by the movement that had been planned to what since had become a distracter. An alternative possibility is that the movement that was produced was a weighted spatial average of movements to the two potential target locations on a given trial. According to either of those explanations, the interference caused by the distracter was a result of some form of response competition stemming from the fact that early in each trial, both target and distracter were viable potential targets. In Experiment 2, we sought to extend these findings to a situation with fewer potential target locations.

EXPERIMENT 2

In Experiment 2, we attempted to replicate the results from Experiment 1 with a reduced number of potential targets. A reduced number of targets would permit more movements to each individual target, which would potentially reduce the impact of a distracter and thus provide a more rigorous test of potential distracter interference effects.

Method

Participants

Six Washington University undergraduates participated in the experiment with the same constraints described in Experiment 1. None had participated in Experiment 1.

Apparatus, Procedure, and Design

The apparatus, procedure, and design were the same as they were in Experiment 1 except that instead of four potential targets, there were three potential targets, with one directly in front of the starting location, and one 23° to the left and another 23° to the right of center. Every combination of target and distracter was equally likely to occur, as in Experiment 1.

Reaching Movement Analysis

The procedures for trajectory analysis were identical to those in Experiment 1 except that here only the movements to the central target were subjected to analysis.

Results

Figure 3 shows mean movement paths for movements to the center target when a distracter was located spatially left or right of the target. Robust dif-

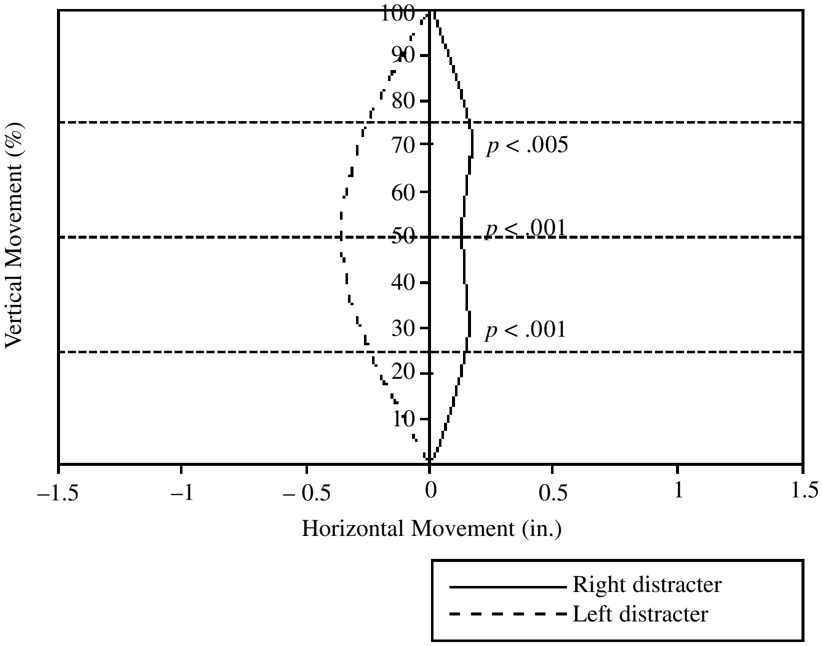

FIGURE 3. Mean movement paths for Experiment 2 shown separately for distracters to the left and right. The *p* values show results of the *t* tests comparing distracter-left and distracter-right conditions at points corresponding to 25%, 50%, and 75% of the distance from the start to the target.

ferences in reach paths depending on the spatial location of the distracter can be seen by the pattern of movements in the two different distracter conditions. As can be seen in Figure 3, the participants' reach paths in the left distracter condition were oriented more leftward compared with those in the right distracter condition.

The movement trajectory data were submitted to a 2 × 2 (Target Color × Distracter Location) ANOVA. For each of the 25%, 50%, and 75% positions, there were significant effects of distracter location: 25%, $F(1, 5) = 32.76$, $p < .01$; 50%, $F(1, 5) = 61.36$, $p < .01$; and 75%, $F(1, 5) = 44.91$, $p < .01$. As we expected, there were no significant effects of target color: 25%, $F(1, 5) = 0.10$, $p = .77$; 50%, $F(1, 5) = 0.42$, $p = .55$; and 75%, $F(1, 5) = 0.92$, $p = .38$, nor were there interactions between target color and distracter location: 25%, $F(1, 5) = 0.54$, $p = .50$; 50%, $F(1, 5) = 1.85$, $p = .23$; and 75%, $F(1, 5) = 0.93$, $p = .38$.

The results of *t* tests comparing the distracter-left and distracter-right conditions are shown in Figure 3 at appropriate locations along the movement path, and they indicate strong reach deviations. Reach paths deviated significantly depending on target–distracter arrangements for all the movement distances: 25%, $t(5) = 5.73$, $p < .001$, 50%, $t(5) = 5.39$, $p < .001$, and 75%, $t(5) = 3.82$, $p < .005$.

As in Experiment 1, the participants did not initiate a movement within 500 ms on 4.95% of trials. Premature responses were observed on 3.06% of trials; the participants missed the target 0.64% of the time. The overall mean RT in the experiment was 417 ms and did not depend on the level of any of the factors, nor were there any interactions.

Discussion

In Experiment 2, we successfully replicated the pattern of results from Experiment 1 under a slightly altered design (i.e., reduced number of targets). As in Experiment 1, the results are consistent with the possibility that competition between a response to the target and a response to the distracter causes the observed deviations. An alternative explanation is considered in Experiment 3.

EXPERIMENT 3

In Experiment 3, we sought to determine whether response competition was necessary to produce deviations toward distracters such as those we observed in Experiments 1 and 2. The participants in Experiment 3 produced movements to a single target throughout the entire experiment. In contrast to Experiments 1 and 2, the distracters in Experiment 3 were never potential targets. Instead, one of two distracters changed color to provide the imperative stimulus—either a *go* or a *no-go* signal. Thus, it was not necessary for a participant to ever plan a movement to more than the sole target location. It is worth noting that the target-defining stimulus dimension was the color of the imperative signal, not its location. Furthermore, we placed the two potential imperative signals very close to the movement starting position and thus far from the movement target. That was done to further reduce the likelihood that the participants would consider the imperative signal to be a potential movement target. If response competition is responsible for the deviations observed in Experiments 1 and 2, then there should not be any such deviations in Experiment 3. However, if the deviations were caused by some alternative mechanism, such as the direction of attention to the distracter, such deviations could still occur.

In addition, to further reduce the likelihood that the participants would prepare a movement to the distracters, we incorporated a new termination task in which they were required to reach for and turn a rotary switch at the end of each movement. Because there was only one switch on the apparatus, there could never be any confusion about the target for the movements, and thus it would be extremely unlikely for the participants to prepare movements to the distracters, which were simply virtual objects on the video display.

Method

Participants

Ten Washington University undergraduates participated in the experiment with the same constraints described in Experiment 1. None had participated in Experiment 1 or 2.

Apparatus

The wooden frame was repositioned to accommodate the stimulus display for the present task (see Figure 4). Instead of a visual target, a rotary switch (diameter = 0.75 in., height = 0.75 in.) was mounted on the far end of the wooden frame (15.75 in. from the starting position). The switch had detents at 30º intervals. Other features of the apparatus were identical to those in Experiments 1 and 2.

Procedure and Design

A circle (0.5-in. diameter) displayed on the screen was used as a starting location and a fixation point (see Figure 4). The participants placed their index fingers on the starting location for a trial to begin, as described heretofore. Figure 4 illustrates the sequence of events in the task. Each of the two circular distracters (1.8-in. diameter) were located 4.25 in. from the starting location (the distracters were thus 27% of the distance from home to target; distracters were located 2.25 in. to the left and to the right of a line connecting the start and target locations). After a 300-ms delay, one of the two distracters changed its color either to red or green for 100 ms. When the distracter color was red, the participants had to refrain from responding (a no-go trial). When the distracter color was green, it was a go trial, and thus the participants reached to turn the switch knob once (30º counterclockwise) for a trial to be considered correct. One should note that the distracter was never a target. Instead, the distracter acted simply as a go or no-go signal that the participants were required to attend in order to respond accordingly.

There was 1 practice block followed by 10 test blocks with 40 trials in each block. The probability of having a distracter at either one of the two possible locations was equal. Half of the trials were go trials and the other half were no-go trials, and the order of trial presentation was random. Every trial condition had an equal probability of occurrence, and all events in a block were randomized.

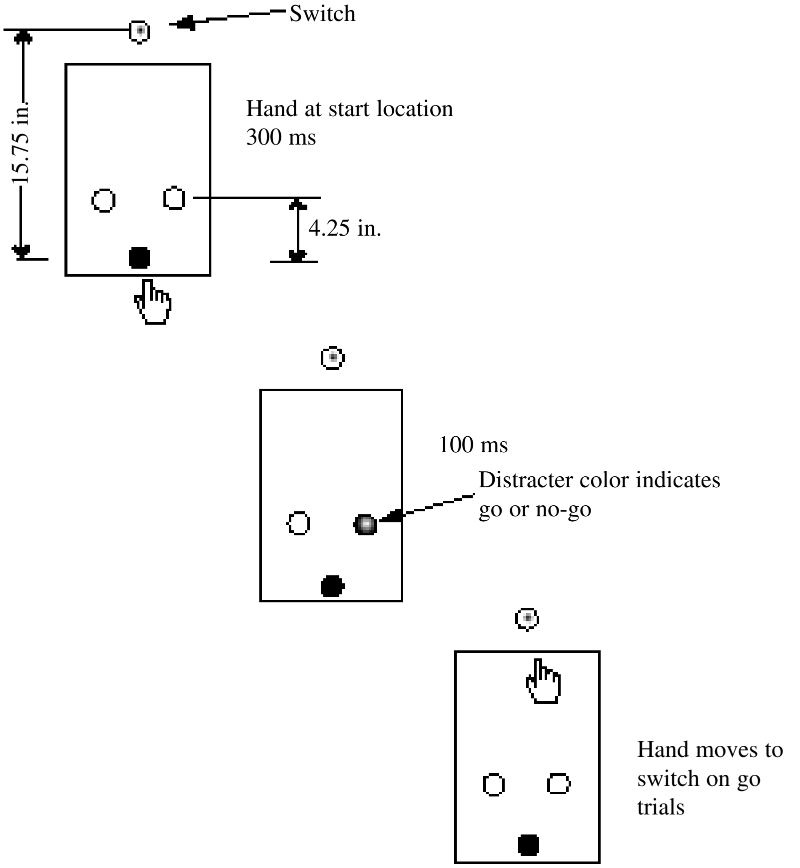

FIGURE 4. The sequence of events in Experiment 3. The goal of each movement was to turn a single switch near the top of the display. Either the right or left distracter would signal go or no-go by color; the distracter position provided no information. The participants were required to reach only on go trials, which was the case whenever the distracter color was green.

Reaching Movement Analysis

The procedure for trajectory analysis was identical to that in Experiments 1 and 2, with the following exceptions. For a trial to be correct, the participants had to turn the switch one detent in the correct direction. Otherwise, the trial was considered erroneous and was not subjected to further analyses. If the hand had traveled more than 1.5 in. in any one of the three dimensions before the go signal was given, then the trial was considered to have an early response error (see Reaching Movement Analysis section in Experiment 1 for details on how the start and the end of movement were defined). In addition, if the hand had not traveled more than 0.05 in. by 500 ms after the go signal was given, then the trial was considered to have a slow start error. The window sizes were reduced slightly from Experiments 1 and 2 to increase the sensitivity for detecting no-go errors because there was only one fixed target location in Experiment 3. Error trials were not included in any further analysis.

Results and Discussion

Figure 5 shows the mean movement paths for distracters to the left and right. The overall shape of the path reflects the appropriate posturing of the hand to accomplish the goal of the movement, turning the switch knob counterclockwise. Consistent with Experiments 1 and 2, the reach paths deviated toward the spatial

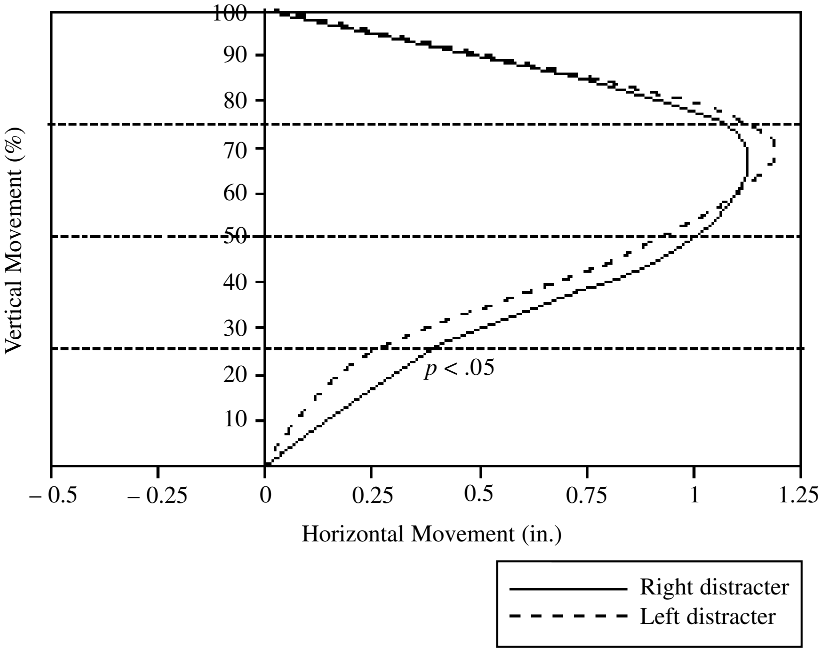

FIGURE 5. Mean movement paths for Experiment 3 when a distracter was to the left or right of the path to the target. Analyses were conducted on the positions at 25%, 50%, and 75% of the distance to the target, with the only difference occurring at 25%.

location of the distracter at 25% of the movement distance, $t(9) = 2.79$, $p < .05$. However, for the 50% and 75% distances, we observed no deviations, $t(9) = 1.12$, $p = .29$, and $t(9) = -0.42$, $p = .68$, respectively.

Error rates were extremely low: 0.09% premature responses; 3.17% late start or no movement; 0.77% incorrect number of switch detents; and 0.27% false start on a no-go trial. The overall mean RT in the experiment was 544 ms and did not depend on the distracter location.

The deviations in the movement trajectories occurred even though the distracters in Experiment 3 were never potential targets. We concluded that movement deviations toward distracters can occur even when there is no response competition occurring between several potential responses. The implications of those results are discussed in the General Discussion.

GENERAL DISCUSSION

In a series of experiments, we had the participants produce reaching movements to targets in the presence of distracters. In Experiments 1 and 2, two potential targets were displayed prior to revealing which was the target and which was the distracter, and reaching movements deviated toward the distracter. In Experiment 3, the participants made a single reaching movement on each trial that terminated in the rotation of a small knob. The imperative stimulus was a light to the right or left of the movement path—but the light itself could never be the target. Nevertheless, the reaching movements were also biased toward the distracter. In Experiments 1 and 2, because the distracters were potential targets, it is possible that response competition produced the observed deviations. For example, the participants might have prepared movements to both potential targets at the beginning of the trial and then selected between them when the true target was revealed. Some residual activation related to the discarded movement plan might then have affected the movement path. Howard, Lupiàñez, and Tipper (1999) reported similar results. Both Welsh et al. (1999) and Howard et al. have described several ways in which response competition such as that described heretofore might affect the trajectories of reaching movements.

Although it is possible that response competition accounts for some of the deviations observed in Experiments 1 and 2, it is unlikely that response competition occurred in Experiment 3. That is because the distracter in Experiment 3 was never a movement target—thus the participants were not likely to have initially prepared movements to both the true target and the distracter. Furthermore, the terminal requirements in Experiment 3 (rotating a knob) could not possibly have been performed on the distracter because the distracter was a light on a video display. Instead, we infer that the distracter exerted its effect in Experiment 3 through some means other than the activation of a response that would later need to be inhibited. One candidate explanation is that the distracter attracted attention, and activity in the spatial attention system affects the representations that are used to plan the reaching movements. Howard and Tipper (1997) have also suggested an attentional explanation for some of their observations involving effects of distracters on reaching movements.

It is worth briefly discussing one possible counterargument that might be offered to our claim that response competition is not necessary to produce deviations of movements toward distracters. The counterargument would be that our participants prepared movements to the distracter in Experiment 3 even though the distracter was not near the target, was not similar to the target, and never was a target. According to that counterargument, people might automatically prepare to make movements to suitable and salient targets that are near them. Thus, the counterargument rejects our claim that there could not be response competition in Experiment 3. However, there are several reasons why we believe that the participants did not prepare movements to the distracter in Experiment 3. First, the two potential distracters were located near the movement start position and far from the target. Second, the terminal action requirements at the target (rotation of a knob) would be impossible to fulfill at the distracter locations (they were lights on a display). Third, the stimulus dimension of color was relevant to the participants, not the spatial location of the color. Fourth, there is no evidence that the mere presence of an object in a scene would evoke a plan to reach for that object. Thus, for the counterargument to be viable, one would have to presume that people would be almost continuously preparing movements to any and all nearby objects in a scene. Such a scenario seems unlikely and is not supported by any evidence.

The evidence of implicit movement preparation is also equivocal in the case of eye movements—a movement type that is arguably more closely linked to visual attention than to limb movements. It is only recently that direct evidence has been presented to suggest a specific neural mechanism that might mediate a link between attention and eye movements (Moore & Armstrong, 2003). But even that result is open to alternative interpretations (Treue & Martinez-Trujillo, 2003). Also, Abrams and Pratt (2000) showed some important differences between the effects of peripheral cues on attentional movements compared with eye movements, which weakens the case for a strong correspondence between the two systems. Of course, whatever the specific mechanism, there is considerable evidence that there is a close relationship between attention and intention (see Snyder, Batista, & Andersen, 2000), so ultimately a complete understanding of movement and attention will specify the details of the relation.

It is interesting to note that in Experiments 1 and 2, we found that the reaching movements were affected by the distracter throughout the movement trajectories (at 25%, 50%, and 75% of the distance to the target), but in Experiment 3, the movements were affected only at 25% of the distance to the target. One possible explanation for that difference is that the additional interference caused by response competition in Experiments 1 and 2 may have resulted in a stronger interference effect than that caused only by attention to the distracter in Experiment 3, presumably without response competition there. Another possibility is related to the location of the distracting objects in the different experiments. In Experiments 1 and 2, the distracters were located close to the targets. Those distracters may have exerted their effects throughout the movement because the hand did not reach their vicinity until the movement ended. But in Experiment 3, the distracters were lights that were close to the starting point, approximately 27% of the distance between the start and the target location. Thus, the distracters may have exerted their effects only until they were no longer a distraction—that is, up to the time that the hand passed their location. After that time, the hand was moving away from them and they were no longer near the path of the movement. The latter interpretation is consistent with the findings of action-based effects that have been reported by several researchers (e.g., Pratt & Abrams, 1994; Tipper et al., 1992). In particular, the distracters affected the movements primarily when they were nearby or along the movement path and not after the movement had passed their location.

It is important for survival that people and other animals can effectively integrate environmental stimuli to specific motor responses, and the mechanisms that do so seem to be universal among different species (e.g., the toad's prey–predator responses, Ewert, 1974; the cricket's abdominal movements, Huber & Thorson, 1985; the moth's bat escape responses, Roeder & Treat, 1957). The deviations in the reaching movements observed in the present study, as well as those observed by others for reaching (e.g., Welsh et al., 1999) and eye movements (Sheliga, Riggio, Craighero, & Rizzolatti, 1995), may reflect the close integration of perceptual and motor systems that is necessary to subserve some of the reflexive movements that are important for survival. We believe that future studies of hand movement paths could provide additional insight into those important mechanisms.

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