Visual Search and Target-Directed Action

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Humans and other visual animals must be able to act selectively in complex visual environments that afford a large number of potential actions. Picking a single apple from a tree containing many apples is a common example used by experimental psychologists who study selective behavior in humans and other primates (Allport, 1987; Castiello, 1996; Neumann, 1987; Van der Heijden, 1990; Van der Heijden & Bridgeman, 1994; Wise & Desimone, 1988). For the present purposes, consider the specific example of picking a ripe (red) apple from a branch when an unripe (green) apple is nearby on the same branch.

It is interesting to see how the study of such real-world problems has been translated into the experimental laboratory. Color visual search tasks are considered experimental analogues of the apple-picking problem. Typically,
participants are instructed to press a button on a computer keyboard or response box as quickly as possible when they detect a target (e.g., a red circle) on a monitor, and the time it takes for them to do so is measured. If the time to respond to the target is longer when distractors (e.g., green circles) are present, then the increase in response time is considered a measure of the amount of time required for selective processes to operate. This interference measure can then be used to study the selective processes more closely. For example, if a distractor at one location produced greater interference than a distractor at another location, then one could conclude that the spatial location of distractors influences the efficiency of the selection system.

The typical finding is that there is little, if any, increase in response time when targets and distractors are discriminated by color, provided the colors can be easily discriminated (Carter, 1982; Duncan, 1989; Treisman & Gelade, 1980; Treisman & Gormican, 1988). Also, the absolute spatial position of a distractor does not seem to influence response time. These findings show that selective processes operate very efficiently when the target differs in color from surrounding distractors.

One could argue, though, that there are many differences between the real world and experimental situations that call into question the validity of the analogy. For example, Goodale (1988), after reviewing color visual search findings, noted:

While this approach to visual perception has proved to be empirically powerful and theoretically rich, it has concentrated almost entirely on the input side of visual processing and has virtually ignored one of the most important functions of vision and the visual system, that of controlling motor output. (p. 263)

To address such an argument, one must design an experimental situation that does a better job of bridging the gap to the real-world situation. Tipper, Lortie, and Baylis (1992) designed such an experimental situation: the selective reaching task.
Figure 1 - Representation of the reaching display used in

Figure 1 is a schematic drawing of the visual display used by
Tipper et al. (1992). At each of the nine locations, there was a response button, a red LED, and a yellow LED. On distractor trials, a red and yellow LED would light at different locations, and participants were instructed to reach for and press the button at the location of the red LED (target) as quickly as possible while ignoring the yellow LED (distractor). There were several fundamental differences between the selective reaching task and search tasks related to the fact that the former more closely approximated how visual information is used by motor systems in the apple-picking task.

- Targets were responded to by reaching to the location of the red light in the selective reaching task rather than pressing a button at a different location (on the keyboard) than the red circle (on the monitor). When
one wants an apple on a tree, one reaches for the location of the apple rather than an arbitrary location at the base of the tree.

- Distractors in the selective reaching task, like targets, were associated with unique responses because there was a response button at each distractor location. In search tasks, no response can be made to distractors. When reaching for apples, it is possible that one could unintentionally reach for an unripe apple.

- If one is to correctly respond in the selective reaching task and in the apple-picking task, information concerning the location of the target must be available. However, in search tasks, it is possible to detect the presence of a target without knowing its location (see Treisman & Gelade, 1980) and to respond without reference to its location.

- In the selective reaching task, targets at different locations require unique responses, whereas, in search tasks, targets at different locations require the same response. When one wants to pick a second apple, one does not reach to the same location where one picked the first apple.

It is possible that these differences were irrelevant. Search tasks could be considered comparable analogues of the apple-picking task if the selective reaching task produced the same results. On the contrary, Tipper et al. (1992) found distractor interference in the selective reaching task, and interference was clearly determined by distractor location. Given that color visual search is performed so efficiently, why is this efficiency compromised when target-directed action is required? The experiments described in this article were designed to explain why distractor interference occurs in the selective reaching task and why distractor location is important. Our hypothesis is grounded in the fact that the identifying features (e.g., color) and the visuomotor features of objects are processed in parallel by the visual system.

**Parallel Visual Pathways for Identification and Action**

In the primate visual system, there are (at least) two parallel cortical streams of visual processing areas beginning in primary visual cortex (V1): a stream that leads ventrally to inferior temporal cortex and a stream that leads dorsally to posterior parietal cortex (Morel & Bullier, 1990). Commonly, the functional specializations of each stream are described in solely visual terms; the ventral stream is specialized for processing the identifying features of objects, and the dorsal stream is specialized for determining the location of objects (Ungerleider & Haxby, 1994; Ungerleider & Mishkin, 1982). Hence, the ventral and dorsal streams are often referred to as the what and where pathways, respectively. Although it had been acknowledged that one of the functions of the dorsal stream was to provide motor systems with visuospatial information, Goodale and Milner (1992) were the first to emphasize its specialized role in action guidance. They suggested that the functions subserved by the dorsal stream were more accurately described as determining how actions were to be performed on an object rather than simply solving the visual problem of determining where the object was located.

The critical visual processing requirement for many visually guided actions (e.g., eye and arm movements) is determination of the spatial location of the target object. For this reason, one might suggest that the how view is difficult to distinguish from the where view. However, actions that have additional visual processing requirements clearly distinguish the two views. For example, consider the distal control of the grasping component of a reach-to-grasp movement. Although the reaching component is critically dependent on the location of the target object, the grasping component requires other visual information such as the shape, size, and orientation of the target object. There is mounting evidence that the dorsal stream processes such visual properties for grasping (Jeannerod, 1994; Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Milner & Goodale, 1993, 1995; Sakata & Taira, 1994; Sakata, Taira, Kusunoki, Murata, & Tanaka, 1997). Such findings are more accurately described by the identification-action distinction than the what-where distinction. Although some aspects of the Goodale-Milner view may be controversial, it is generally accepted that vision for identification and vision for action are processed quasi-independently and in parallel by the primate brain (see also Boussaoud, di Pellegrino, & Wise, 1996).

It is also important to note that vision-for-action processing is not limited to the dorsal stream. First, dorsal stream areas project to a multitude of specialized cortical and subcortical areas. Examples include frontal
cortical areas such as the frontal eye fields (FEF) in the eye movement system (Bullier, Schall, & Morel, 1996; Schall, Morel, King, & Bullier, 1995) and dorsal premotor cortex (PMd) in the arm movement system (Caminiti, Ferraina, & Johnson, 1996; Johnson, Ferraina, Bianchi, & Caminiti, 1996; Wise, Boussaoud, Johnson, & Caminiti, 1997). Second, the pathway leading from the retina to the lateral geniculate nucleus and V1, or the retinogeniculate pathway, is not the only vision-for-action pathway; direct projections from the retina to superior colliculus (SC) constitute a second vision-for-action pathway (Wurtz & Albano, 1980). This retinotectal pathway also provides a secondary source of inputs to the dorsal stream via the pulvinar (see Milner & Goodale, 1995, for a review). In summary, while vision-for-identification areas process the identifying features of an object, such as color or form, vision-for-action areas concurrently process visual information for the control of actions afforded by that object, such as eye movements, reaching movements of the arm, or grasping movements of the hand.

**Selection in Identification and Action Pathways**

People's visual environment often contains many objects, only a fraction of which are relevant. Under such conditions, selective processes enable the identification and action pathways to perform their respective functions. Selective processes enable the differentiation of relevant objects from irrelevant objects varying in their identifying features and the specification of movements to relevant objects among irrelevant objects varying in their action affordances. Consider the apple-picking problem: Which apple is picked can be determined by its color, size, shape, or other distinguishing features (e.g., absence of wormholes). Each apple has its own distinguishing features signifying desirability (an identity selection problem), and each has its own action specifications (an action selection problem). If the desired apple is to be picked, the products of identity selection must inform vision-for-action networks.

Neurophysiological studies of identity selection in nonhuman primates (Chelazzi, Miller, Duncan, & Desimone, 1993) have led to the suggestion that coordinated bottom-up and top-down selective processes enhance or suppress ventral stream representations of objects with or without relevant identifying features, respectively. When one is searching for a red object among non-red objects, for example, interobject competition in the ventral stream is biased toward red objects by feature-selective mnemonic processes of lateral prefrontal cortex (Chelazzi, 1995; Desimone, 1996; Desimone & Duncan, 1995).

Operating in parallel with identity selection processes, vision-for-action pathways process all potential targets in complex visual scenes. For accurate specification of the target action, target identity information must be communicated to vision-for-action networks, where target activity must be isolated (by target enhancement, distractor suppression, or both). Because vision-for-identification processing is slow relative to vision-for-action processing (Schmolesky et al., 1998), distractors can evoke activity at advanced stages along vision-for-action pathways before target and distractor activity is modulated (see the Discussion section). Such distractor competition can have measurable behavioral effects on the performance of target-directed actions.

**The Visuomotor Processing Hypothesis**

On the basis of these properties of the visual system, we suggest that interference in the selective reaching task can be explained by visuomotor competition from distractors. Why is distractor location an important determinant of the degree of interference in selective reaching? Visuomotor processing is more efficient in producing reaching movements to stimuli appearing at some locations than at others. In other words, after a given period of time following stimulus presentation, the level of visuomotor representation achieved by that stimulus depends on its spatial location. Hence, the faster a reaching movement can be made to a location, the greater the advancement of the visuomotor representation of a distractor appearing at the location (when information becomes available for selection), and the greater the interference caused by the distractor.

Previous findings of location interference are consistent with this hypothesis. Figure 1 is a schematic drawing of the visual display used by Tipper et al. (1992). For reaches from the starting position shown (at the front of the display) to targets in the middle row (Locations 4, 5, and 6), there was more interference...
from distractors in the front row (Locations 1, 2, and 3) than from distractors in the back row (Locations 7, 8, and 9). The starting position of the hand was then moved to the rear of the display (above the back row shown in Figure 1) while the body was maintained in the same position so that participants were reaching toward the body. The results were the opposite from this rear starting position: Back row distractors interfered more than front row distractors. In other words, the starting position of the hand had a profound influence on the spatial nature of the interference.

These findings are commonly attributed to the fact that the interfering distractors are positioned along the path of a reach to the target (Castiello, 1996; Goodale & Milner, 1992; Pratt & Abrams, 1994; Rizzolatti, Riggio, & Sheltiga, 1994; Tipper et al., 1992). However, Meegan and Tipper (1998) showed that the greater interference was due to the distractors' proximity to the starting position of the hand rather than their position relative to the reaching path. In other words, distractors near the starting position of the hand caused substantial interference regardless of whether they were located on the reaching path, and distractors on the reaching path did not cause substantial interference when they were further from the starting position. This finding was referred to as the proximity-to-hand effect.

Which hand is used to respond also influences interference. Tipper et al. (1992) found that when the right hand was used to reach for a target in the middle of the display (Location 5 of Figure 1), there was more interference from a distractor to the right of midline (Location 3) than from a distractor to the left (Location 1). But when the left hand was used to reach for the same target, there was more interference from the left than the right distractor. Meegan and Tipper (1998) referred to this finding as the ipsilateral effect.

The visuomotor processing hypothesis suggests that the faster a reaching movement can be made to a location, the greater the interference from a distractor at that location. This hypothesis can explain both the proximity-to-hand and ipsilateral effects because there is evidence of visuomotor processing advantages for near relative to far and ipsilateral relative to contralateral locations (see Meegan & Tipper, 1998).

There is an alternative explanation for interference, however. Although it is commonly assumed that there is no interference from distractors in color visual search, there is ample evidence for interference when colors are not easily discriminated (e.g., Carter, 1982; Duncan, 1989; Treisman & Gormican, 1988). Interference in the selective reaching task could thus be due to a serial search (Treisman & Gormican, 1988) or an inefficient parallel search (Duncan & Humphreys, 1989). Although this offers a possible explanation for interference effects in general, it cannot explain why distractors at certain locations cause more interference than distractors at other locations, unless there was some bias to the former locations. In other words, some aspect of the selective reaching procedure may have biased visual processing to those locations at which distractors caused more interference.

The experiments presented here were designed to determine whether location interference effects are due to visuomotor rather than visual biases. Experiments 1 and 2 used manipulations that influenced the efficiency with which reaches could be made to various locations. The critical test was whether a decrease in the visuomotor processing efficiency of reaches to a target location (an increase in response time) corresponded to a decrease in interference from distractors at the same location (on reaches to other target locations). The findings supported the visuomotor processing hypothesis.

**Experiment 1**

Tipper et al. (1992) found substantial changes in spatial interference when the starting position of the reaching hand was moved from the front to the back of the display. The visuomotor processing hypothesis would suggest that such interference changes occurred because shifting the starting position produced corresponding changes in the speed of reaching to the affected locations. Because they did not report response times for reaches to the target locations from the front and back starting positions, our hypothesis could not be evaluated post hoc. As a means of testing our hypothesis, Experiment 1 also manipulated the starting position of the hand. The main prediction of our hypothesis was that any changes in interference due to hand position would correspond to changes in visuomotor efficiency.
**Method**

**Participants**

Forty undergraduate students (12 men and 28 women) from McMaster University participated in the experiment for course credit. All participants were right-handed, had normal color vision, and had normal or corrected-to-normal acuity, and all used their right hand for the experiment. Experiments 1A and 1B were run coincidentally, and participants were pseudorandomly assigned to use the front (1A) or back (1B) starting position.

**Apparatus**

No chin rest was used because arm movements can be disrupted when the head is restricted (Biguer, Jeannerod, & Prablanc, 1985), and we wanted to mimic naturalistic reaching conditions as much as possible. The distance of the eyes from the display thus varied across participants. For this reason, the dimensions of the reaching display are given in actual rather than retinal size. The apparatus (area = 51 cm²), represented in Figure 1, was raised to an angle of approximately 30° from the horizontal and placed on a table 14 cm from the front edge. It was interfaced to a computer that controlled stimulus lights and recorded response times and errors. The display configuration consisted of a subset of the stimulus-response locations shown in Figure 1. In all experiments, Locations 3, 1, 4, and 6 of Figure 1 were the front-right, front-left, back-right, and back-left locations, respectively. Note that the descriptions front, back, left, and right indicate locations relative to the torso of the participant rather than relative to the starting position of the hand. Front row or back row is sometimes used to describe the two front or two back locations. The size of the response buttons was 17 mm²; 29 cm separated the right from the left locations, and 13.5 cm separated the front and back rows. Two small lights, one red and one yellow, were positioned adjacent to each other directly below each button.

The starting positions were at the start location for Experiment 1A and at Location 8 for Experiment 1B; both locations were 13.5 cm from the center of the nearest row (see Figure 1). Locations 2, 5, 7, and 9 were not visible in either experiment.

**Procedure**

There were 16 trial types: 1 no-distractor (target-only) control trial type and 3 distractor trial types for each of the four target locations. Twenty trials of each type appeared randomly for each participant (total: 320 trials).

Response time for each correct trial was measured from the time the stimulus light(s) appeared until the target button was pressed. An error was recorded if the distractor button was pressed. Interference scores for each participant in each distractor condition were calculated in the following manner. Initially the median response time was determined for each trial type. The difference between response time for each target-distractor combination and its respective control (response time to that target without a distractor) was then calculated. Multiple distractor trial types were combined into one distractor condition by calculating a mean of the difference scores in that condition.

The participants sat in front of the display under dim illumination and were told to get in a position where they could comfortably reach all four keys with their right hand. They were asked to maintain a body posture such that the body midline was in line with the start button and the shoulder line was parallel to the front edge of the board. In Experiment 1B, participants were additionally instructed to hold their right arm toward the center of the display so that the right forearm or elbow did not block the view of the front-right stimulus location. Participants were instructed to press the start and target buttons with the tip of the index or middle finger. They were instructed that on each trial a red light would appear under one of the four buttons and that on some trials a yellow light would appear at a different location. They were instructed to press the button above the red light as quickly as possible while ignoring the yellow light. Each trial began...
with the participant pressing and holding the start key with the right hand. A pause (approximately 600 ms) occurred between start key depression and stimulus onset. After the pause, the target and distractor (or target alone) appeared and remained on until the participant completed the response. After the response, the participant could initiate the next trial at any time. The computer gave an error tone if the participant pressed the wrong key or if the start key was released before stimulus onset. In the latter case, the trial was repeated. After a 10-trial demonstration from the experimenter, the participants completed 20 practice trials chosen randomly from the 16 trial types. After the practice trials, participants completed 320 experimental trials.

**Results**

**Experiment 1A**

Experiment 1A was run coincidentally with Experiment 1B, and the two experiments were compared to assess the influence of hand starting position. First, however, we wanted to ensure that the results of Experiment 1A were consistent with those of Meegan and Tipper (1998). In other words, we expected to find both ipsilateral and proximity-to-hand effects in the distractor interference and target response time data of Experiment 1A.

We expected more interference from front than back distractors (proximity to hand) and more interference from right than left distractors (ipsilateral). Mean interference scores were submitted to a $2 \times 2$ analysis of variance (ANOVA) with distractor hemispace (right vs. left) and distractor row (front vs. back) as variables (see
Figure 2 - Mean target response time (top) and distractor interference (bottom) for Experiment 1 as a function of stimulus location and hand starting position. The shaded hand represents back row starting position and the unshaded hand represents the front row starting position.

Figure 2). There was a main effect of row; front row distractors \((M = 24 \text{ ms})\) interfered more than back row distractors \((M = 13 \text{ ms})\), \(F(1,19) = 7.91, p < .02\). There was also a main effect of hemispace; right distractors \((M = 24 \text{ ms})\) interfered more than left distractors \((M = 13 \text{ ms})\), \(F(1,19) = 20.94, p < .001\). The interaction of hemispace (ipsilaterality) and row (proximity to hand) was not significant, \(F(1,19) = 3.13\). These results replicated the interference results from Meegan and Tipper (1998).

We also expected that the response time data for the control (target-only) trials would conform to the visuomotor processing hypothesis. In other words, as in Meegan and Tipper (1998), we expected that response time would be less for reaches to front row and right hemispace targets than to back row and left hemispace targets, respectively. Mean response times for control trials were submitted to a 2 \(\times\) 2 ANOVA with target hemispace (right vs. left) and target row (front vs. back) as variables (see Figure 2). There was a main effect of row; response time to front row targets \((M = 632 \text{ ms})\) was less than to back row targets \((M = 690 \text{ ms})\), \(F(1,19) = 191.52, p < .0001\). There was also a main effect of hemispace; response time to right targets \((M = 645 \text{ ms})\) was less than to left targets \((M = 678 \text{ ms})\), \(F(1,19) = 42.70, p < .0001\). There was no Row \(\times\) Hemispace interaction \((F < 1)\). These results were consistent with the hypothesis that interference from a distractor at a given location was determined by the speed with which a response could be generated to a stimulus at that location.

As in Meegan and Tipper (1998), we expected that more errors would be made to locations associated with greater distractor interference. All 20 participants combined made only 10 errors (0.16% of trials). Such a small number of errors is difficult to analyze statistically. However, the greatest number of errors (4) were made to the front-right location (proximate and ipsilateral to the reaching hand), the fewest errors (1) were made to the back-left location (distant from and contralateral to the hand), and intermediate numbers of errors were made to the front-left (2) and back-right (3) locations.

Experiments 1A and 1B

Target response time as a function of hand starting position.

To determine how manipulating hand position influenced visuomotor processing efficiency of reaches to the four locations, we submitted mean response times for control trials to a 2 \(\times\) 4 mixed ANOVA with hand position (front vs. back) and target location (front left vs. back left vs. front right vs. back right) as variables (see Figure 2). There was a significant Hand Position \(\times\) Stimulus Location interaction, \(F(3,114) = 169.51, p < .0001\). Simple effects analyses (Keppel, 1982) revealed that this interaction was due to the fact that reaching to the front-right location was slower when the hand reached from the back position \((p < .0001)\) than from the front, and reaching to the back-left location was faster from the back position \((p < .01)\) than from the front; reaches to the other two locations were not affected by hand position.

Distractor interference as a function of hand starting position.

According to our hypothesis, there should have been a similar Hand Position \(\times\) Location interaction for distractor interference. Mean interference scores were submitted to a 2 \(\times\) 4 mixed ANOVA with hand position (front vs. back) and distractor location (front left vs. back left vs. front right vs. back right) as variables (see Figure 2). There was a significant Position \(\times\) Location interaction, \(F(3,114) = 9.03, p < .001\). As expected from the target response time results, simple effects analyses revealed that this interaction was due to the fact that interference from the front-right distractor was less when the hand started its reach from the back position \((p < .002)\) than from the front position, and interference from the back-left distractor...
was (marginally) greater for the back position ($p = .0509$) than for the front; interference from the other two distractor locations was not affected by hand position.

**Errors.**

As in Experiment 1A, errors in Experiment 1B were minimal and thus difficult to analyze. All 20 participants combined made only seven errors (0.11% of trials). Two errors were made to the front-left, back-left, and back-right locations, and one error was made to the front-right location.

**Summary.**

Hand-position-based changes in interference from distractors at certain locations corresponded to changes in the visuomotor processing efficiency of reaches to targets at those locations.

**Experiment 2**

Despite the consistency of the results of Experiment 1 with the visuomotor processing hypothesis, it remained possible that there were biases to those locations at which distractors produced greater interference. Examples include biases of saccadic eye movements, covert attentional orienting, initial fixation position, and the orientation of the head and body relative to the display. The visual or proprioceptive presence of the arm or hand in a region of space could also bias processing to that region. Finally, a region of space, defined by action parameters, could receive enhanced attentional processing relative to other regions; such an explanation was used to explain the findings of Tipper et al. (Rizzolatti et al., 1994; see also Goodale & Milner, 1992). Experiment 2 was designed to specifically test our hypothesis by ensuring that the hypothesis made a prediction that was unique from these alternatives.

There is one primary commonality among these alternatives: They all suggest that the spatial properties of the interference effects were products of visual processing biases to certain regions of space. Our account is similar in that it also explains the spatial properties of the interference effects as products of processing biases to certain regions of space. What makes our hypothesis unique is that the processing biases implicated are visuomotor rather than visuospatial in nature. The reason our account has not yet been able to uniquely explain differences in interference produced by different stimuli is that those stimuli have been defined by their spatial locations (e.g., right vs. left and front vs. back). However, visuomotor processing differences between different visual stimuli need not be based on differences in spatial location. In other words, it is possible that two stimuli at the same location could differ in terms of the nature of the visuomotor processing required to generate a reaching movement to that location. If interference differed between two stimuli that differed in visuomotor but not visuospatial aspects, then our hypothesis would be distinguished from the alternative hypotheses. Experiment 2 was designed to create such an experimental situation.

How can one manipulate the relative visuomotor processing efficiency of two different reaches to the same visual location? We manipulated the complexity of reaches to a location, because complexity and efficiency are inversely related. Complexity was increased by placing a transparent plastic obstacle in front of the response button. To press the target button, participants had to reach over the top of the obstacle. Except for the difference in movement complexity, everything about the obstacle-present and obstacle-absent conditions should have been the same: use of the right hand, the starting position of the hand, the position of the right arm, the location of the stimuli, the location of the response, the position of the head and body, the focus of covert attention, the position of the stimulus relative to the eyes, and so forth.

The critical comparison was between a condition in which the obstacle was present at the critical location and a condition in which the obstacle was not present at the location. We expected that the obstacle would increase response time for reaches to the location relative to reaches to the same location when the obstacle was absent. Except for the difference in movement complexity, everything about the obstacle-present and obstacle-absent conditions should have been the same: use of the right hand, the starting position of the hand, the position of the right arm, the location of the stimuli, the location of the response, the position of the head and body, the focus of covert attention, the position of the stimulus relative to the eyes, and so forth.
What did the different hypotheses predict for interference from a distractor at the obstacle location relative to a distractor at the same location when the obstacle was absent? Our hypothesis predicted that the obstacle-present distractor would interfere less than the obstacle-absent distractor because the motor processing efficiency of a reach to the obstacle location was reduced. The alternative hypothesis, which implicated differences in visuospatial processing efficiency, predicted no difference in interference from obstacle-present and obstacle-absent distractors, because both distractors were visually and spatially identical. A confirmation of our prediction would constitute strong support for the suggestion that irrelevant visual distractors were represented as actions, because the only parameter that differed between the obstacle-present and obstacle-absent distractors was the nature of the action afforded by each.

**Method**

**Participants**

Thirty-six undergraduate students (11 men and 25 women) from McMaster University participated in the experiment for course credit. All participants were right-handed, had normal color vision, and had normal or corrected-to-normal acuity, and all used their right hand for the experiment. Experiments 2A and 2B were run coincidentally, and participants were pseudorandomly assigned to perform in either the obstacle-absent (2A) or obstacle-present (2B) condition.

**Apparatus**

The display used in the obstacle-absent condition (Experiment 2A) was identical to that used in Experiment 1A. The display used in the obstacle-present condition (Experiment 2B) was also identical, except that a transparent plastic half-dome (cut from a transparency sheet for overhead projectors) was fastened to the board in front of the front-right button (Location 3 of Figure 1). This obstacle was placed such that it was in front of the button but not the target and distractor lights below it. It was completely transparent, and vision of the button and lights was not occluded. At its peak above the center of the button, the obstacle was 54 mm; its width was 33 mm in front of the button and fanned out to 70 mm toward the rear.

**Procedure**

The only special instruction given to participants in the obstacle-present condition was that they were to avoid touching the obstacle by reaching over the top of it. The procedure was otherwise identical to that of Experiment 1A.

**Results**

**Experiment 2A**

We first wanted to confirm that the results from the obstacle-absent condition were consistent with the identical hand-at-front condition from Experiment 1. We expected more interference from front than back distractors (proximity to hand) and more interference from right than left distractors (ipsilateral). Mean interference scores were submitted to a $2 \times 2$ ANOVA with distractor hemispace (right vs. left) and distractor row (front vs. back) as variables (see
Figure 3 - Mean interference for Experiment 2 as a function of distractor location and obstacle condition. The shaded area represents the obstacle present at front-right location and the unshaded area represents the obstacle absent.

Figure 3). There was a main effect of row; front row distractors ($M = 26 \text{ ms}$) interfered more than back row distractors ($M = 15 \text{ ms}$), $F(1,17) = 6.89, p < .02$. There was also a main effect of hemispace; right distractors ($M = 25 \text{ ms}$) interfered more than left distractors ($M = 15 \text{ ms}$), $F(1,17) = 22.04, p < .001$. The interaction of hemispace (ipsilaterality) and row (proximity to hand) was not significant, $F(1,17) = 2.21$. These results replicated the interference results from Experiment 1A (cf. Figures 2 and 3).

We also expected that response time would be less for reaches to front row and right hemispace targets than for reaches to back row and left hemispace targets, respectively. Mean response times for control trials were submitted to a $2 \times 2$ ANOVA with target hemispace (right vs. left) and target row (front vs. back) as variables (see Figure 4 - Mean target response time (top) and distractor interference (bottom) for Experiment 2 as a...
function of stimulus location and obstacle condition. Interference excludes reaches to the front-right target. The shaded area represents the obstacle present at front-right condition and the unshaded area represents the obstacle absent.

Figure 4). There was a main effect of row; response time to front row targets \((M = 610 \text{ ms})\) was less than to back row targets \((M = 665 \text{ ms})\), \(F(1,17) = 212.87, p < .0001\). There was also a main effect of hemispace; response time to right targets \((M = 624 \text{ ms})\) was less than to left targets \((M = 652 \text{ ms})\), \(F(1,17) = 32.71, p < .0002\). There was no Row \(\times\) Hemispace interaction \((F < 1)\). These results replicated the target response time results from Experiment 1A (cf. Figures 2 and 4).

All 18 participants combined made only 19 errors (0.33% of trials). As in Experiment 1A, the greatest number of errors (9) were made to the front-right location, the fewest errors (2) were made to the back-left location, and intermediate numbers of errors were made to the front-left (5) and back-right (3) locations. As expected, the results were very consistent with the results of Experiment 1A.

**Experiments 2A and 2B**

**Target response time as a function of obstacle condition.**

The complexity manipulation was designed to increase response time of reaches to only the front-right location in the obstacle-present condition. To test whether this manipulation was successful, we submitted mean response times for control trials to a 2 \(\times\) 4 mixed ANOVA with obstacle condition (present vs. absent) and target location (front left vs. back left vs. front right vs. back right) as variables (see Figure 4). As expected, there was a significant Condition \(\times\) Location interaction, \(F(3,102) = 77.88, p < .0001\). Simple effects analyses revealed that this interaction was due to the fact that response time to the front-right location in the obstacle-present condition \((M = 752 \text{ ms})\) was slower \((p < .0001)\) than in the obstacle-absent condition \((M = 596 \text{ ms})\); response times to the other three locations did not differ between conditions.

**Distractor interference as a function of obstacle condition.**

According to our hypothesis, there should have been a similar Obstacle Condition \(\times\) Location interaction for distractor interference. Mean interference scores were submitted to a 2 \(\times\) 4 mixed ANOVA with obstacle condition (present vs. absent) and target location (front left vs. back left vs. front right vs. back right) as variables (see Figure 3). There was a significant Condition \(\times\) Location interaction, \(F(3,102) = 4.75, p < .005\). As expected from the target response time results, simple effects analysis revealed that interference from a distractor at the front-right location was reduced \((p < .05)\) in the obstacle-present condition relative to the obstacle-absent condition.

The Condition \(\times\) Location interaction also seemed to be partly due to an increase in interference from the other three distractor locations in the obstacle-present condition (see Figure 3), although the simple effects analyses showed that this increase was significant only for the back-right location \((p < .05)\). A closer examination of the data revealed that this increase was due to heightened interference from the front-left (63 ms), back-left (54 ms), and back-right (58 ms) distractors specifically for reaches to the front-right target in the obstacle-present condition. This finding was consistent with our hypothesis because, as a result of the motor processing disadvantage caused by the obstacle, the front-right target was less competitive and thus more susceptible to interference from distractors at the other locations. When reaches to the front-right target were excluded, there were no longer any differences in interference between the obstacle-present and obstacle-absent conditions for the front-left, back-left, and back-right distractors (see Figure 4).

**Errors.**

The error data for the obstacle-absent condition have been presented. In the obstacle-present condition, all 18 participants combined made only six errors (0.10% of trials). No errors were made to the front-right
location in the obstacle-present condition, as compared with the nine errors made to the front-right
distractor in the obstacle-absent condition. Such a decrease in errors corresponded to the increase in
target response time and the decrease in distractor interference when the obstacle was at the front-right
location. Two errors, three errors, and one error were made to the front-left, back-left, and back-right
locations, respectively, in the obstacle-present condition.

**Summary.**

The obstacle successfully decreased motor processing efficiency (i.e., increased response time) of
reaches to the front-right target. As predicted by the visuomotor processing hypothesis, this decreased
motor processing efficiency also produced a decrease in interference from a distractor at the front-right
location. Because the front-right distractors in the obstacle-present and obstacle-absent conditions were
visually and spatially identical, this finding is very difficult to explain using alternative hypotheses claiming
that selective reaching interference effects are products of visuospatial biases. These findings provided
strong support for our suggestion that distractors achieve action representations, because the only
difference between the front-right distractors in the obstacle-present and obstacle-absent conditions was
the nature of the action afforded by each.

**Experiment 3**

To this point, it has been assumed that the spatial properties of the interference effects were a product of
the use of reaching responses. Even the aforementioned alternatives to the visuomotor processing
hypothesis included this assumption in suggesting that spatial biases were due to reaching-related aspects
of the experiments. Experiment 3 tested the validity of this assumption. Such a test was necessary
because it was possible that there was something unique to the task or display, but not related to reaching
responses, that produced the spatial interference effects. Examples of such factors—albeit examples that
have been discounted in other experiments—include spatial asymmetries in search-and-detect tasks
(Previc & Blume, 1993; Yund, Efron, & Nichols, 1990) and intensity differences among the LEDs on the
reaching display.

Visually, the task used in Experiment 3 was almost identical to that used in Experiments 1A and 2A, but
the responses were not reaching responses. Instead, participants had to localize targets by making verbal
responses associated with the target locations; the locations were numbered, and the response time to
name the target number was measured.

If it is true, as we have assumed, that selective reaching interference effects are due to the use of reaching
responses, then the interference effects in the verbal task should not show the same spatial properties as
those in reaching tasks. Thus, in contrast to the results of Experiments 1A and 2A, we expected that right
distractors would not interfere more than left distractors and that front distractors would not interfere more
than back distractors.

**Method**

**Participants**

Twenty-four undergraduate students (5 men and 19 women) from McMaster University participated in the
experiment for course credit. All participants were right-handed, had normal color vision, and had normal or
corrected-to-normal acuity, and all used their right hand for the experiment.

**Apparatus**

The stimulus board in the experiment was the same as in Experiments 1A and 2A. The numbers 1, 2, 3,
and 4 appeared at the four stimulus locations. The numbers were printed in black, centered on a white
paper background (17 mm²), and fastened to the buttons at the locations. The vertical extent of each number was 14 mm, and the horizontal extent varied from 8 mm (7) to approximately 10 mm (2, 3, and 4). A clip-on microphone was interfaced to the computer via a voice-key interface that detected the onset of an utterance into the microphone.

**Procedure**

For each of the 24 participants, the locations of the numbers were chosen randomly (without replacement) from the 24 possible combinations of the four numbers at the four locations, so that each of the 24 combinations was used once in the experiment. This was done for two reasons. First, there may have been differences in how quickly participants could say, for example, 2 relative to 3. If 2 and 3 appeared at the same locations for all participants, then the spatial nature of response time differences to the locations would be confounded. Second, participants may have more quickly learned the association between a particular number (e.g., 1) and its location and thus would have been faster to say that number when a target appeared at the location. If 1 appeared at the same location for all participants, then response time results would be similarly confounded.

It was important that the verbal task was the same as the reaching task in every respect except for the type of response. In the reaching task, the right hand not only reached for and localized the target; it also began each trial from a starting position at the body midline. It is possible that the placement of the right hand at the starting position could have unwanted influences on the results. For example, relative to when the right hand is not at the starting position, the torso or head could be turned slightly, despite our attempts to eliminate such spatial biases in Experiments 1 and 2 through instructions and monitoring by the experimenter. As a means of ensuring that such possible influences were the same in the verbal and reaching tasks, the right hand was maintained at the same starting position used in Experiments 1A and 2A.

In the reaching task, it was possible that participants could have initiated reaching responses on some trials without foveating the target location. However, in the verbal task, if participants did not learn the numbers associated with the locations, then it was not likely that they could have initiated accurate responses without foveating the target locations and reading the numbers. Thus, to satisfy the requirement that the verbal task be as similar as possible to the reaching task, it was hoped that participants learned the number-location associations. To this end, the number of practice trials was increased from 20 to 50. During the break after the first half of the experimental trials, participants were asked whether they were responding without reading the number at the target location, and all participants responded affirmatively.

As in Experiments 1 and 2, there were 16 trial types: 1 no-distractor (target-only) control trial type and 3 distractor trial types for each of the four target locations. Twenty-four trials of each type appeared randomly for each participant (total: 384 trials). Pilot work indicated that procedural differences in the verbal task decreased the likelihood that trials would produce usable response times; more trials per condition were used in the verbal task to ensure that the number of usable trials in the verbal task was comparable to the number in the reaching task.

One procedural difference was that the experimenter had to listen to the verbal response of the participant and enter that response into the computer keyboard. On some trials, the experimenter could not clearly hear which of the four numbers was spoken, and such trials could not be used. Also, on rare occasions (three in total), the experimenter mistakenly entered a number other than that spoken by the participant. The computer program coded these trials as participant errors and did not record the response times for the trials.

A second procedural difference was related to the sensitivity of the microphone and the voice key for detecting sounds. A small light on the voice-key device indicated to the experimenter when a sound had been detected. If it was clear to the experimenter that the voice key detected a sound before the participant made a vocal response (i.e., an extraneous sound was detected), or if the voice key did not detect the initial vocal response, then the trial was not used.
Voice-onset time for each usable trial was measured from the time the stimulus light(s) appeared until the voice key detected an utterance into the microphone. We calculated interference scores for each participant in each distractor condition as in the previous experiments, using voice-onset time rather than reaching response time.

Errors in the verbal task were not easily comparable to errors in the reaching task because of the manner in which they were coded by the computer program running the experiment. In the reaching tasks, an error indicated a trial on which the distractor button was pressed. In the verbal task, a trial was coded as an error when a number other than the target number was entered into the computer keyboard by the experimenter. There were two problems. First, on three occasions, the experimenter erroneously entered a number other than that spoken by the participant. Second, the computer did not code what was entered into the computer; it only coded that something other than the target number was entered. In other words, it cannot be assumed that the response on an error trial was the distractor number; evidence against such an assumption comes from the fact that 17.8% of errors in the verbal task occurred on trials on which no distractor was present. Because of these two problems, an error may have been something other than a response to the stimulus at the distractor location. Errors in the verbal task could thus not be compared with errors in the reaching task. They are presented but not discussed.

The microphone was clipped to the participant’s shirt. The participants were instructed to begin each trial by pressing and releasing the start key with the tip of the index or middle finger of the right hand and to keep the hand at this position throughout each trial. They were also instructed to respond as quickly as possible by clearly saying the number corresponding to the target location. After stimulus presentation and response, the experimenter pressed the character on the keyboard that corresponded to the verbal response. Unusable trials (as defined earlier) were coded by pressing another key on the computer keyboard. Participants rested for several minutes after 192 of the experimental trials had been completed and then completed the remaining 192 trials. In all other respects, the procedure was the same as that used in Experiments 1A and 2A.

Results

Across participants, 1.45% of trials were coded as unusable. No participant had more than five combined errors and unusable trials for any one trial type. Three errors were experimenter errors.

Distractor Interference

In contrast to the results of Experiments 1A and 2A, we expected that right distractors would not interfere more than left distractors and that front distractors would not interfere more than back distractors. As in Experiments 1A and 2A, mean interference scores were submitted to a 2 × 2 ANOVA with distractor hemispace (right vs. left) and distractor row (front vs. back) as variables. Mean interference from distractors at the four locations was as follows: front right, 58 ms; front left, 60 ms; back right, 77 ms; and back left, 82 ms. There was no interaction of hemispace and row, $F(1,23) < 1$. There was also no main effect of hemispace, $F(1,23) < 1$; in other words, there was no difference in interference from right ($M = 68$ ms) and left ($M = 71$ ms) distractors. This finding was consistent with our prediction that right distractors would not interfere more than left distractors. There was a main effect of row; back row distractors ($M = 80$ ms) interfered more than front row distractors ($M = 59$ ms), $F(1,23) = 15.60, p < .001$. This finding was consistent with our prediction that front distractors would not interfere more than back distractors.

Target Response Time

Although we were primarily concerned with how interference results from the verbal task compared with interference from the reaching task, we also present the target response time data from the verbal task. Perhaps, as in reaching tasks, distractor interference was inversely related to target response time. If this is true, then response time to back targets should have been faster than to front targets, and response time to right and left targets should have been the same. Mean response times were submitted to a 2 × 2
ANOVA with target hemispace (right vs. left) and target row (front vs. back) as variables. Mean voice-onset times to targets at the four locations were as follows: front right, 677 ms; front left, 677 ms; back right, 623 ms; and back left, 644 ms. There was no interaction of hemispace and row, \( F(1,23) = 1.03 \). There was also no main effect of hemispace, \( F(1,23) = 1.10 \); in other words, there was no difference in response time to right \( (M = 650\text{ ms}) \) and left \( (M = 661\text{ ms}) \) targets. There was a main effect of row; back row targets \( (M = 634\text{ ms}) \) were responded to faster than front row targets \( (M = 677\text{ ms}) \), \( F(1,23) = 16.57, p < .001 \). As in reaching tasks, participants’ susceptibility to interference from a distractor corresponded to their ability to respond quickly to a target at the same location.

It is interesting that verbal responses to back row targets were quicker than responses to front row targets. The types of visuomotor factors underlying spatial asymmetries in reaching tasks probably do not underlie such asymmetries in the verbal task; some type of visual bias to the back row is a more likely possibility. The possibility of visuospatial rather than visuomotor biases in the verbal task does not weaken our argument for visuomotor biases in reaching tasks, however, because we assume only that visuomotor factors will play a role in directed actions, such as eye, hand, and arm movements, known to be subserved by specialized vision-for-action pathways. Comparatively little is known about the neural substrate underlying verbal responses to visual stimuli. If anything, a visual bias in the verbal task strengthens our argument because it implies that the visuomotor bias to front row stimuli in reaching tasks exists despite a potential visual bias to back row stimuli.

**Errors**

Three of the errors presented here were experimenter errors. For trials on which a distractor was present, 24, 35, 28, and 19 errors (for the 24 participants combined) occurred when a distractor appeared at the front-left, back-left, front-right, and back-right locations, respectively. For trials on which only a target was present, the corresponding numbers of errors were 7, 5, 5, and 6.

**Summary**

As expected, the spatial interference results of the verbal task used in Experiment 3 differed from those of the reaching task used in Experiments 1A and 2A. Given that the verbal task was almost identical to the reaching task in every respect other than the nature of the response, it is safe to assume that the differences in interference between the two experiments were a result of the response differences. In other words, the spatial properties of the interference effects found in selective reaching tasks are probably a product of the use of reaching responses.

**Discussion**

The combined results of Experiments 1 and 2 confirmed that spatial aspects of distractor interference in a reaching task were not determined by visual biases to the locations of distractors. Experiment 3 confirmed that these spatial aspects of interference were unique to a reaching task by showing that the same spatial interference effects were not seen when verbal responses were used to localize targets on the same visual display. The visuomotor processing hypothesis suggested that spatial aspects of interference were due to visuomotor processing biases to the locations of distractors. This hypothesis was confirmed in Experiment 2 when two distractors at the same location produced different degrees of interference because of differences in their visuomotor properties. This finding provided strong support for our suggestion that distractors achieve action representations, because the only difference between the two distractors was the nature of the action afforded by each.

**Neurophysiological Investigations of Visual Search and Target-Directed Action**

In the introduction, we noted that the parallel nature of the visual system can result in advanced visuomotor
representations of distractors during identity search. Ideally, the results reported here would be complemented by neurophysiological evidence of distractor activity in vision-for-action areas of the reaching system. Unfortunately, neurophysiologists have not yet sought to document such activity. For the saccade system, on the other hand, there is an abundance of neurophysiological research on distractor visuomotor activity during identity search. Thus, the saccade system is a model for understanding the neural mechanisms underlying visual search and target-directed action. First, we should note that distractors can influence behavioral measures in saccade tasks as in reaching tasks. For example, Ottes, Van Gisbergen, and Eggermont (1985) had human participants move their eyes to a green target in the presence of a red distractor. Saccade response time was longer and saccade direction was modified in the presence of the distractor.

More direct evidence for visuomotor processing of distractors comes from single neuron activity recorded while monkeys direct saccades to targets defined by identity. Vision-for-action neurons in the saccade system code space. Near the visual end of the visual-to-motor continuum, a neuron might respond to a potential saccade target appearing in its receptive field (RF); closer to the motor end, a neuron might respond to a stimulus whose acquisition requires a saccade in its preferred direction. Between these extremes, many neurons respond initially to stimuli appearing in their fields and subsequently preceding and during saccades directed to their fields.

Some identity search studies have made direct comparisons between activity evoked by targets and distractors appearing in the fields of saccade neurons. If some time is indeed required before target identity information can be communicated to vision-for-action networks, then the initial activity of these neurons should be the same for targets and distractors. Subsequently, selective modulation should result in greater activity for targets than distractors. Such patterns of activity have been recorded in three critical areas of the saccade system: the lateral intraparietal area (LIP), FEF, and SC.

Platt and Glimcher (1997) recorded from LIP neurons during a task in which monkeys directed gaze to one of two peripheral visual stimuli. A change in color of a central fixation stimulus indicated which of the two stimuli was the saccade target and which was the distractor. During the 200-ms period immediately after the occurrence of the target identity cue, there was no difference between target and distractor activity (M. L. Platt, personal communication, January 19, 1998). Subsequently, in the 200-ms period immediately preceding a go signal for the target saccade, distractor activity was suppressed such that target activity was significantly greater than distractor activity.

Schall and colleagues have investigated FEF activity during tasks in which monkeys direct gaze to targets defined by color or form (Schall & Hanes, 1993; Schall, Hanes, Thompson, & King, 1995). On a typical trial, they presented a circular array of eight stimuli (surrounding a central fixation stimulus) containing a saccade target that differed in color or spatial frequency from the other seven. The FEF neurons they examined began to respond shortly after presentation of a visual stimulus in their movement fields and remained active until saccades were made into their fields. After the onset of stimuli, enhanced activity occurred for both targets and distractors, and this activity was no greater for targets. Subsequently, before saccade initiation, only targets produced enhanced activity.

Ottes, Van Gisbergen, and Eggermont (1987) examined the activity of vision-for-action neurons in SC during a task in which monkeys directed gaze to targets defined by color. The monkeys were trained to refixate a green spot of light after its offset at a central fixation position and onset at a peripheral location; on some trials, a red distractor appeared simultaneously at another peripheral location. The neurons responded to visual stimuli appearing in their visuomotor fields and before and during saccades to the location of their fields. The initial response, within 100 ms of stimulus onset, was the same for targets and distractors. A subsequent presaccadic burst of activity occurred only when a target was in the visuomotor field.

Glimcher and Sparks (1992) examined distractor activity at a later stage of the saccadic system in monkey SC prelude burster neurons, which display low-frequency activity before saccades made to their movement fields. As in the aforementioned task of Platt and Glimcher (1997), the color of a central fixation stimulus indicated which of two peripheral stimuli was the saccade target. Although distractor activity was minimal relative to target activity, it appeared that an initial prelude spike in response to stimulus onset was comparable for targets and distractors in the movement field; subsequent prelude activity was much greater.
for targets (detailed activity from only one neuron was reported). The possibility of even a minor onset response to the distractor is particularly noteworthy when certain methodological details are considered. Unlike in the Platt and Glimcher study, the target identity cue appeared 300-600 ms before the peripheral stimuli, and activity was not recorded until the peripheral stimuli appeared. Because the cue was roughly predictive of target and distractor location—it indicated the hemifield (upper or lower) in which the target would appear and that the distractor would appear in the opposite hemifield—spatial selective processes could have influenced target and distractor activity.

The findings just reviewed show that distractors can evoke activity at advanced stages of the saccadic system during identity search. Other studies have shown that experience with search arrays can influence this activity. Bichot, Schall, and Thompson (1996) examined FEF activity as in previously discussed studies conducted by Schall and colleagues. An experimental group of monkeys was trained to search exclusively for a target of one color among distractors of a different color (e.g., red among green), and a control group was trained to search for the oddball color in different search displays (e.g., red among green and green among red). As in other studies, neurons of the control group showed comparable initial activity for targets and distractors. In contrast, 21 of 47 neurons of the experimental group showed greater initial activity for targets than distractors. Interestingly, these differences in initial activity were due to attenuated distractor activity rather than enhanced target activity. Bichot et al. (1996) suggested the possibility that distractor attenuation "is mediated by a reduction in the synaptic efficacy of neurons representing the constant distractor feature" (p. 699).

Because FEF neurons are known to code location rather than identity, the finding that some FEF neurons have an attenuated initial response to identity-defined distractors is remarkable. There could be several factors underlying this finding. Bichot et al. (1996) raised the possibility of experience-induced feature selectivity in FEF neurons. Alternatively, feature-selective neurons in vision-for-identification areas could have been affected; rapid access is provided by direct connections between vision-for-identification areas and FEF (Bullier et al., 1996; Schall, Morel, et al., 1995). The activity of feature-selective neurons of lateral prefrontal cortex, for example, provided evidence for a pretrial target advantage under similar, exclusive-target conditions (Rainer, Asaad, & Miller, 1998). During a block of 80 trials in which the same identity-defined target was used, neurons preferring the target's identifying features had a higher baseline firing rate than neurons preferring other identifying features. Short-term mnemonic processing can also produce a target advantage in ventral stream neurons when there is a brief delay period between presentation of a target identity cue and the onset of targets and distractors (Chelazzi et al., 1993).

A related issue concerns stability in natural visual scenes. In the studies reviewed here, trials were discrete, and new stimuli were presented in each trial. However, in natural scenes, visual stimuli generally do not appear in such a fashion. Consider again the apple-picking task; the experiments reviewed here mimic the unnatural situation in which one approaches the tree with eyes closed and then suddenly opens them before picking. Gottlieb, Kusunoki, and Goldberg (1998) overcame this problem by displaying a stable array, consisting of a circle of eight stimuli differing in form and color, for prolonged periods (more than 10 min or 100 trials) while recording from monkey LIP neurons. A stimulus entered an RF not by a discrete onset at the RF location but, rather, by an eye movement that brought the RF to the stimulus location. Interestingly, the response of the neuron when the stimulus entered the RF in this manner was attenuated relative to the discrete onset case.

A relevant question concerns the consequences of this attenuation for distractor activity in LIP. In one task, an initial eye movement brought the RF to the location of a potential target for a second eye movement. The initial neural response to the potential target stimulus was attenuated. Gottlieb et al. (1998) then presented a target identity cue near the new fixation point (outside of the RF). Selective modulation—specifically, enhancement of target activity—could be seen approximately 300 ms after cue onset (detailed activity from only one neuron was reported). In other words, because distractor activity and target activity were attenuated in advance, selective processes acted primarily to enhance target activity. By contrast, selective processes also acted to suppress unattenuated distractor activity in previously reviewed studies using discrete onset stimuli.

With a second task, Gottlieb et al. (1998) showed that the effects of selective processing (i.e., target enhancement) could be seen even before the target or distractor entered the RF. It is an interesting
characteristic of LIP that RFs can shift location in anticipation of an eye movement (Duhamel, Colby, & Goldberg, 1992). In the Gottlieb et al. task, the target identity cue was presented before a predictable eye movement that brought the RF to the location of a target or distractor. Target enhancement seemed to begin before the eye movement (detailed activity from only one neuron was reported). This finding is not surprising given that the time between cue onset and the eye movement was ample for identity information to reach LIP (500-700ms).

In summary, targets and distractors evoke activity in saccadic areas during identity search. Selective modulation favoring the target occurs after target identification. When target and distractor identity are known in advance, distractors are less likely to evoke saccadic activity. When the search array is visible for prolonged periods, saccadic activity associated with all stimuli is attenuated, and only target enhancement is necessary to direct action to the target once its identity is known.

**Visuomotor Pathways for Reaching**

Although distractors can achieve advanced saccadic representations during identity search, one might argue that the same cannot be assumed for the reaching system because visual-to-motor transmission is less direct for arm than eye movements. The retinogeniculate pathway is known to subserve both arm and eye movements, but the retinotectal pathway is commonly thought to subserve only eye movements. Recent investigations of reaching neurons in SC, however, have opened up the possibility that the retinotectal pathway may also provide visual information for arm movements (Werner, 1993; Werner, Hoffmann, & Dannenberg, 1997).

Furthermore, visual-to-motor transmission for reaching via the retinogeniculate pathway is quite direct. In the macaque, PMd is a particularly important frontal motor area for visually guided arm movements (Passingham, 1993; Wise, 1985). The dorsal stream is linked to PMd via posterior parietal cortex (Caminiti et al., 1996; Johnson et al., 1996; Wise et al., 1997). Tanné, Boussaoud, Boyer-Zeller, and Rouiller (1995) also reported a direct projection to PMd from the parietal-occipital area (PO), a visual area in the dorsal stream (see also Matelli, Luppino, D'Amelio, Fattori, & Galletti, 1995; Shipp & Zeki, 1995). Given that PO (sometimes called V6) receives direct projections from V1 (Colby, Gattass, Olson, & Gross, 1988), visual information from V1 could be as little as two corticocortical synapses removed from PMd.

Evidence for the automatic transmission of information along such visuomotor pathways comes from three sources: (a) visuomotor priming, (b) visuomotor behavior after brain damage, and (c) visuomotor processing without awareness. First, there is evidence that visuomotor pathways can be primed. For example, grasping efficiency has been shown to be facilitated by the prior presentation of a task-irrelevant object that was visually congruent with the object to be grasped (Craigiero, Fadiga, Umiltà, & Rizzolatti, 1996). Similarly, it has been shown that, in judgments of the orientation of graspable objects, faster manual keypress responses are made with the hand most compatible with grasping the objects in their presented orientation (Tucker & Ellis, 1998). These findings show that merely seeing an object can unintentionally activate visuomotor processes.

Further evidence for automatic visual-to-motor transmission comes from studies of human patients with frontal lobe damage who are impaired in their ability to withhold unintended motor responses to visual objects (e.g., Lhermitte, 1983). Such behavior is thought to be caused by damage to the mechanisms responsible for controlling the consequences of normal, automatic visual-to-motor transmission. Similar explanations have been used to describe unintended, goal-directed arm movements in alien hand syndrome following frontal and callosal damage (Riddoch, Edwards, Humphreys, West, & Heafield, 1997).

Although goal-directed movements to visual objects are generally under cognitive control in the nondamaged brain, the automaticity of visual-to-motor transmission has led to the suggestion that vision-for-action pathways can be considered modular in the Fodorian sense (Goodale, 1988). In support of this view, there are numerous examples of visuomotor processing without conscious awareness (Milner & Goodale, 1995). For example, rapid adjustments of arm movements to changes in location of visual stimuli can occur without participants being consciously aware of the stimulus changes or of the motor adjustments (Bridgeman, Lewis, Heit, & Nagle, 1979; Goodale, Pelisson, & Prablanc, 1986; Prablanc &

The preceding findings suggest that visual information can be passed to motor areas without a conscious intention to act on the information. Consider then the efficiency of visuomotor processing when there is an intention to act; movement intention probably facilitates information transmission along visuomotor pathways. In summary, the efficiency of visual-to-motor transmission in the reaching system leads us to speculate that distractors can achieve visuomotor representations in reaching identity search as they do in saccade identity search.

Conclusions

There have been many behavioral investigations of the ability to search for and detect the presence of identity-defined targets in complex visual scenes. Neurophysiological investigations with nonhuman primates have provided some insight into the neural mechanisms underlying this ability, specifically in vision-for-identification areas. However, most identity search tasks do not adequately represent those real-world situations in which directed actions must be made to targets. Behavioral studies requiring target-directed action, such as the reaching experiments reported here, reveal that performance cost can be attributable to visuomotor competition from distractors. Also, neurophysiological studies have provided neural evidence for competition from distractors in visuomotor areas. This visuomotor competition is a byproduct of the fact that vision for identification and vision for action are processed quasi-independently and in parallel in the primate brain. In conclusion, we suggest that future models of visual selective attention, aspiring to apply to real-world situations such as picking a ripe apple among unripe apples, must take into account the act of picking itself.

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