

Interference from Distractors in Reach-to-grasp Movements

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Descriptions of interference effects from non-relevant stimuli are extensive in visual target detection and identification paradigms. To explore the influence of features of non-relevant objects on reach-to-grasp movements, we instructed healthy normal controls to reach for and pick up a cylinder (target) placed midsagittally 30 cm from the starting position of the hand. In Experiment 1, the target was presented alone, or accompanied by a narrower, wider, or same-size distractor positioned to the left or right of the target. In Experiment 2, the target was presented alone or accompanied by a distractor, which was slanted at a different orientation to the target. Reflective markers were placed on the wrist, thumb, and index finger of the right hand, and infra-red light-detecting cameras recorded their displacement through a calibrated 3-dimensional working space. Kinematic parameters were derived and analysed. Consistent changes in the expression of peak velocity, acceleration, and deceleration were evident when the distractor was narrower or wider than the target. The impact of the orientation of the distractor, conversely, was not marked. We discuss the results in the context of physiological findings and models of selective attention.

In daily life, goal-directed actions such as reaching to grasp are executed in the presence of task-irrelevant (“distractor”) objects—for example, items scattered on a desk when reaching for a cup of coffee. Whereas some studies report marked disruption of reach-to-grasp parameters in the presence of distractors, others report no alterations. Evaluation of the literature is difficult, because studies are few and heterogenous. Even so, several points arise. Speed of movement execution, knowledge of the target prior to movement

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initiation, and target characteristics (such as location and size) may be critical in revealing interference effects. Moreover, studies vary on the parameters reported, thus interference effects may be an artifact of the group of parameters chosen for reporting.

Interference effects from non-relevant stimuli have been studied extensively in visual identification paradigms (for example, Eriksen & Eriksen, 1974; Lavie & Tsai, 1994; Stroop, 1935; Underwood, 1976). The study by Tipper, Lortie, and Baylis (1992) marks a paradigm shift, from reaction time in visual detection and identification to selective reaching. Under speeded movement conditions, reaction times increase, and accuracy of responses to target buttons is reduced in the presence of a distractor (Tipper et al., 1992; Pratt & Abrams, 1994), and the decelerative component of the movement is extended (Pratt & Abrams, 1994). Conversely, Castiello (1996), using non-speeded aiming movements and fruit as stimuli, does not report distractor interference. Thus, interference effects may depend on the number, shape, and positioning of stimuli, and the speed and accuracy requirements of the reach.

The relatively small literature on distractor interference in reach-to-grasp paradigms suggests that reaction time and movement duration are increased in the presence of distractors (Tipper, Howard, & Jackson, 1997), peak wrist velocity to the target is reduced, deceleration time increases, and grasp aperture is smaller (Jackson, Jackson, & Rosicky, 1995). Furthermore, the trajectory of the reach is altered: The hand deviates away from a proximal distractor and forms a trajectory of higher altitude (Howard & Tipper, 1997; Tipper et al., 1997). Importantly, the alterations in the trajectory are not evident when the target is cued 300 msec in advance of movement initiation (Tipper et al., 1997), suggesting a key role for coding of target and distractor prior to movement initiation.

Bonfiglioli and Castiello (1998) show that interference effects in the grasp, but not transport, parameters are observed only when the distractor is smaller than the target. Specifically, peak grasp aperture and grasp aperture opening velocity are reduced, and peak grasp aperture occurs later in the course of the movement. This implies that the intrinsic properties of a distractor (such as its size, colour, and orientation), and not simply the extrinsic property of location, may elicit competing responses and thus have a selective influence on kinematic parameterization.

Tipper and colleagues (Howard & Tipper, 1997; Tipper et al., 1997; Tipper, Howard, & Meegan, 1998) propose that volumetric properties of distractors are calculated for successful guidance of the hand through space. Their model is based on evidence of activation of parietal and inferotemporal cortical neuronal populations (Chelazzi, Miller, Duncan, & Desimone, 1993; Georgopoulos, 1990; Kalaska, 1988; Kalaska, Caminiti, & Georgopoulos, 1983). It assumes that distinct neuronal populations activate to target and distractor location, and that these populations may overlap. If the activation associated with the distractor is suppressed, the neurones in common with the target-related population will also be suppressed. This causes interference, because the averaged output of the target population is altered. Putatively, this will manifest as an alteration in the movement execution parameters.

In summary, it is yet unclear under which conditions interference effects manifest reliably. Overall, four points emerge for consideration. First, there are some indications that knowledge of the stimulus layout *prior* to movement initiation does not lead to

interference (Tipper et al., 1997). Second, speed and accuracy may be crucial for the observation of interference effects (Howard & Tipper, 1997). Third, features of the stimuli such as position and size of the distractor also require consideration (Bonfiglioli & Castiello, 1998; Tipper et al., 1997). Finally, on a methodological level, the set of kinematic parameters reported has not been consistent across studies. If interference effects manifest reliably in some parameters but not others, the conflicting findings across studies may not be surprising.

EXPERIMENT 1

Based on the behavioural evidence and the neuronal activation model outlined above, we ask specific questions regarding the nature of interference effects and the conditions in which they manifest. First, Tipper et al. (1997) showed that interference effects may depend on knowing which is to be the target prior to movement initiation. Does the same apply to prior knowledge of the distractor? Watson and Humphreys (1997) presented targets (letters on a monitor) simultaneously with distractors, or after a delay. Reaction times to targets increased when they appeared simultaneously with distractors, but not when targets appeared 400 msec or more after the distractors. In this study, we hold the target features and location constant and vary the distractor. We postulate that when the distractor location and features are unknown prior to movement initiation, interference effects will arise, because the selective attention processes coupling perception and action in the planning and execution of the movement are incomplete (Tipper et al., 1997). As a result, the kinematic parameterization may be inappropriate to the target in terms of movement duration, velocity, grasp aperture, and the timing of temporal parameters. For example, as we discuss in greater detail below, the expression of these parameters may be more appropriate to the size of the distractor than the target.

Second, we compare directly reaches executed at normal as opposed to fast speed. The paradigms of Tipper and colleagues (Howard & Tipper, 1997; Tipper et al. 1997) involved speeded movements, but Castiello (1996) and Bonfiglioli and Castiello (1998) did not instruct participants as to the speed of movement. Speed requirements may place different constraints on the calculation of volumetric properties of the stimuli and on the coordination and execution of reach-to-grasp parameters. During fast movements in the presence of distractors, therefore, we expect alterations in trajectories, such that they deviate away from the distractor (Howard & Tipper, 1997; Tipper et al., 1997). According to Tipper and colleagues, increased curvature of trajectories should be evident if the neuronal populations activated for distractor and target position overlap.

Our third line of investigation concerns the size of the distractor. If volumetric properties of target and distractor are calculated (Tipper et al., 1997), a systematic relationship between size of distractor and degree of trajectory deviation should be evident. As well as trajectory parameters, however, grasp parameters should alter when a distractor of different size to the target is present, because two competing grasp programmes are elicited. We know from single-cell recordings in primates that populations in the anterior cortex activate differentially to object sizes as well as to grasp types (Rizzolatti et al., 1988; Taira, Georgopoulos, Murata, & Sakata, 1990), suggesting size- and shape-specific programming of grasp parameters. Moreover, interference is restricted to grasp, rather than

transport parameters when the distractor is smaller than the target (Bonfiglioli & Castiello, 1998). If there is a systematic effect of distractor size, grasp aperture will be smaller and will occur earlier in the presence of a smaller distractor than with a same-size distractor and the target presented alone. By the same token, in the presence of a larger distractor peak grasp should be greater and occur later.

Finally, the dependent variables described by Tipper and colleagues are quite different from those reported by Castiello (1996) and Bonfiglioli and Castiello (1998). Apart from movement duration and initiation time, Tipper et al. (1997) and Howard and Tipper (1997) describe the trajectory of the hand, whereas Castiello (1996) and Bonfiglioli and Castiello (1998) describe alterations in velocity, acceleration, deceleration, and grasp aperture, as well as temporal parameters. It is possible that interference effects manifest in specific subsets of reach-to-grasp parameters. In the present study, we report movement duration and the amplitude and temporal values of velocity, grasp, and trajectory parameters, to reflect a range of previous studies (Bonfiglioli & Castiello, 1998; Howard & Tipper, 1997; Jackson et al., 1995; Tipper et al., 1997).

Method

Ten normal healthy participants (five females, five males; mean age 20.7 years, $SD = 3.65$) completed the experiment as part of their course credit. All participants were right-handed, had normal or corrected-to-normal vision, and were ignorant as to the purpose of the experiment.

Apparatus and Materials

Participants were seated at a table (50 cm \times 90 cm). The target was a red wooden cylinder (height 10 cm, diameter 1.2 cm) placed 30 cm from the starting switch, on the midsagittal plane. It was presented either alone or flanked by a distractor. The distractor was also a red wooden cylinder the same height as the target, but either the same diameter, narrower (diameter 0.7 cm), or wider (diameter 1.8 cm) than the target. It was presented 30 cm from the starting switch and 20° (polar coordinates) to the right or left of the target.

We controlled visual availability of the stimuli with lightweight spectacles fitted with liquid crystal lenses (Plato Technologies Inc.). In half of the blocks, the lenses were always clear. In the other half of the blocks the opacity of the lenses was controlled by the circular starting switch (diameter 10 cm, height 1 cm) on which the hand rested: When the hand was positioned on the switch the lenses were opaque, and they cleared on movement initiation. As well as controlling the lenses, release of the starting switch also signalled movement initiation to the computer.

Participants always performed prehension movements with their right hand. Hemispherical reflective passive markers (0.25 cm diameter) were attached to the wrist (radial aspect of the distal styloid process of the radius), the index finger (radial side of the nail), and the thumb (ulnar side of the nail).

Procedure

Participants rested the ulnar side of their right hand on the starting switch, ensuring that the hand was positioned midsagittally in the frontal plane and 15 cm from the trunk. The pads of the right index finger and thumb were held in gentle opposition, and the right shoulder was flexed 5–10°. The

right elbow was also flexed, the right forearm was semipronated, and the right wrist was extended 10–15°. Participants were instructed to begin moving only on hearing the auditory start signal (80 Hz, 100 msec), which was delivered at irregular intervals of between 5 and 10 sec. They were required to pick up the centrally placed cylinder with a precision grip, between the index finger and thumb, to lift it approximately 20 to 30 cm above the table-top, and then to return it to approximately its original position. Each block of reaches was preceded by five practice trials.

Prehension movements were recorded under two visual conditions (“constant vision” and “limited vision”) and two speed conditions (“normal speed” and “fast speed”). In the constant vision condition, the lenses of the Plato spectacles were always clear, thus participants were able to view the placement of the cylinder(s) prior to movement initiation. In the limited vision condition, however, the lenses of the Plato spectacles were initially white and opaque, so that participants were unable to see the placement of the cylinder(s) prior to movement initiation. When participants lifted their hand from the starting switch, the lenses became clear and transparent. In the normal speed condition, participants were instructed to reach out and grasp the target cylinder at natural speed. In the fast speed condition, they were instructed to reach out and grasp the target cylinder as fast as they could.

Thus, the four combinations of visual and speed of movement conditions were as follows:

Constant Vision, Normal Speed. Participants were able to view the experimenter placing the cylinder(s) prior to movement initiation of each reach, and they performed the movement at natural speed.

Limited Vision, Normal Speed. Participants were unable to view the experimenter placing the cylinder(s) prior to movement initiation of each reach, and they performed the movement at natural speed.

Constant Vision, Fast Speed. Participants were able to view the experimenter placing the cylinder(s) prior to movement initiation of each reach, and they performed the movement as fast as possible.

Limited Vision, Fast Speed. Participants were unable to view the experimenter placing the cylinder(s) prior to movement initiation of each reach, and they performed the movement as fast as possible.

Data Analysis and Design

Each of the four conditions was administered as a block of 40 trials. Randomized within each block were 10 trials for which the target was presented alone (“target alone”), 10 trials for which the target was presented with a distractor of the same size (“target plus same distractor”; 5 ipsilateral and 5 contralateral presentations), 10 trials for which the target was presented with a distractor of smaller size (“target plus smaller distractor”; 5 ipsilateral and 5 contralateral), and 10 trials for which the target was presented with a distractor of larger size (“target plus larger distractor”; 5 ipsilateral and 5 contralateral). The order of presentation of each condition was randomized between subjects.

It is evident in the literature that the hemispace location of the target relative to the distractor has differential effects for left- versus right-hand reaches (Howard & Tipper, 1997; Jackson et al., 1995). In this series of experiments, however, we collapsed across left and right distractor presentations primarily because we were interested in the role of intrinsic features (size, orientation), rather than extrinsic features (location) of targets and distractors. Moreover, using this approach we were able to keep the number of factors in the analysis and therefore the number of comparisons to a minimum.

Because we were interested in specific comparisons between conditions, we conducted planned contrasts rather than an overall ANOVA (Hays, 1981). Due to the heterogeneity of paradigms and parameters reported in previous literature, we were unable to make predictions about the likely direction of significant effects in all parameters. Thus we chose to report the F ratio rather than the t ratio for the comparisons (Hays, 1981).

The comparisons were as follows. All constant vision trials were collapsed across speed of movement and distractor presentation and compared with limited vision trials (likewise collapsed across speed of movement and distractor presentation). All normal speed of movement trials were collapsed across vision and distractor presentation and compared with fast speed of movement trials (likewise collapsed across vision and distractor presentation).

For each of the four conditions, three planned contrasts were conducted: Each type of distractor presentation (“target plus same distractor”, “target plus smaller distractor”, “target plus larger distractor”) was compared with “target alone”. Only the contrasts that reached significance will be reported for each parameter.

Data Recording and Processing

Movements were recorded with the ELITE system (Ferrigno & Pedotti, 1985), using two infrared cameras (sampling rate 100 Hz). The calibrated working space was a parallelepiped from which the spatial error measured from stationary and moving stimuli was 0.4 mm. Coordinates of the markers were reconstructed with an accuracy of 1/3000 for the vertical (Y) axis and 1.4/3000 for the two horizontal (X and Z) axes.

The data were processed using a modified version of the Eligrasp (BTS, 1994) software package, which gave a three-dimensional reconstruction of the marker positions. The data were filtered with a FIR linear filter—transition band of 1 Hz (sharpening variable = 2; D’Amico & Ferrigno, 1990, 1992). X and Y marker displacements and the resultant velocity and acceleration profiles were determined. Movement initiation was taken from the release of the starting switch. The end of movement was taken as the time when the fingers closed on the target, and there was no further change in the distance between the index finger and thumb. Movement duration was the time (in milliseconds) from movement initiation to the end of movement.

Dependent Variables

Movement duration (time from release of the starting switch to end of grasp) was calculated. Peak velocity, peak grasp aperture, and the absolute values for peak lateral and vertical deviations, as well as the time to each of these peaks as a percentage of movement duration, were calculated from the trajectory profiles of the wrist marker. Peak grasp and time to peak grasp were based on the distance between the index and thumb markers.

Results

Figure 1 shows typical velocity curves (Panel A) and trajectories (Panels B and C) of subject MT for reaches to the target when it was presented alone, or with same-size, smaller, or larger distractors.

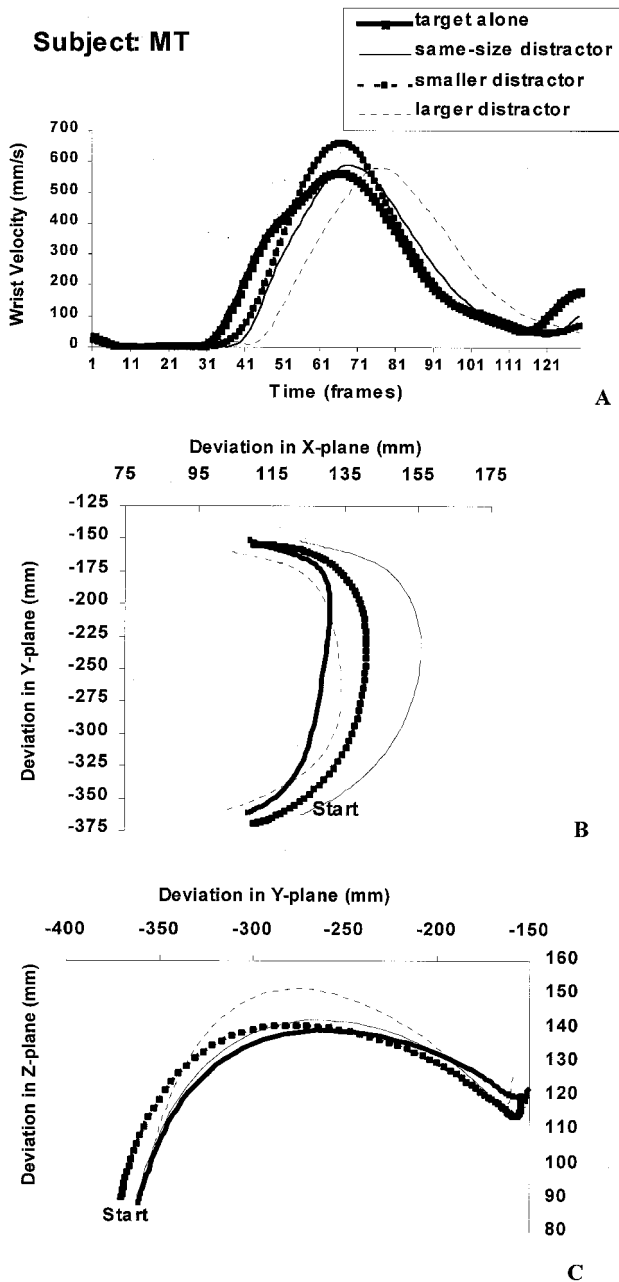


FIG. 1. Typical subject reaching with his right hand for a midsagittally-placed target presented alone, or with a same-size distractor, smaller distractor, or larger distractor. Panel A shows the velocity profiles of the reaches. Panels B and C show the pathway of the hand in the XY (lateral) and YZ (vertical) planes, respectively. (Note: One frame = 10 msec).

Visual Availability and Speed of Movement

As expected, manipulation of the visual availability of targets and distractors, and the speed of movement execution influenced most of the reach-to-grasp parameters (see Tables 1 and 2, respectively). Under limited vision conditions, movement duration increased and the amplitude of peak velocity decreased. These parameters, and peak grasp, also occurred at a relatively later point in the course of the movement.

Not surprisingly, when participants performed the movement as fast as possible, movement duration decreased, and the amplitudes of peak velocity and peak grasp increased. They occurred, however, at the same relative point as movements performed at normal speed. As regards trajectory parameters, peak vertical deviation decreased and both peak vertical deviation and peak lateral deviation occurred significantly later in the movement phase than they did when movement was performed at normal speed.

Thus, although movements were performed at an increased speed, alterations in the relative organization of movement were restricted to trajectory parameters. Visual availability prior to movement initiation, conversely, did alter the temporal programming and organization parameters of reach-to-grasp actions.

Target Alone versus Target with Same-Size Distractor

Constant Vision, Normal Speed. Peak lateral deviation was attained significantly earlier, and movement duration was significantly decreased when the target was accompanied by a distractor of the same size than when the target was presented alone: lateral deviation, $F(1, 9) = 12.48$, $p < .01$, see Figure 2; movement duration, $F(1, 9) = 7.01$, $p < .05$, see Figure 3.

TABLE 1
Distractor size: The influence of movement speed on prehension parameters, for Experiment 1

	<i>Speed</i>		
	<i>Normal</i>	<i>Fast</i>	<i>F(1, 9)</i>
movement duration ^a	925.15 (121.75)	556.16 (56.49)	124.74****
peak velocity ^b	606.43 (130.71)	904.36 (149.98)	89.28****
% time to peak velocity	47.45 (3.57)	49.88 (6.19)	2.82*
peak lateral deviation ^c	20.34 (9.84)	18.88 (10.22)	0.381
% time to peak lateral deviation	51.13 (3.76)	53.63 (5.02)	8.38*
peak vertical deviation ^c	64.02 (23.38)	55.49 (17.24)	11.03**
% time to peak vertical deviation	59.22 (7.16)	70.14 (10.26)	29.37****
peak grasp ^c	55.29 (6.28)	68.62 (7.51)	44.83****
% time to peak grasp	62.79 (3.37)	61.83 (3.75)	0.86

^a In msec. ^b Mm/sec. ^c Mm.

* $p < .05$ ** $p < .01$ *** $p < .001$ **** $p < .0001$

Note: Values in parentheses are standard deviations.

TABLE 2

Distractor size: The influence of visual availability on prehension parameters for Experiment 1

	Vision		
	Constant	Limited	<i>F</i> (1, 9)
movement duration ^a	697.63 (65.31)	783.68 (98.75)	873.73****
peak velocity ^b	813.45 (151.92)	697.34 (116.19)	34.14****
% time to peak velocity	45.78 (4.79)	51.55 (4.76)	33.34****
peak lateral deviation ^c	17.75 (8.69)	21.48 (11.00)	2.99
% time to peak lateral deviation	52.71 (4.69)	52.06 (4.10)	0.67
peak vertical deviation ^c	59.02 (18.93)	60.49 (22.09)	0.31
% time to peak vertical deviation	64.83 (9.75)	64.53 (8.26)	0.02
peak grasp ^c	62.92 (6.62)	60.99 (6.21)	2.94
% time to peak grasp	61.65 (3.24)	62.97 (4.21)	1.05

^a Msec. ^b Mm/sec. ^c Mm.**** $p < .0001$

Note: Values in parentheses are standard deviations.

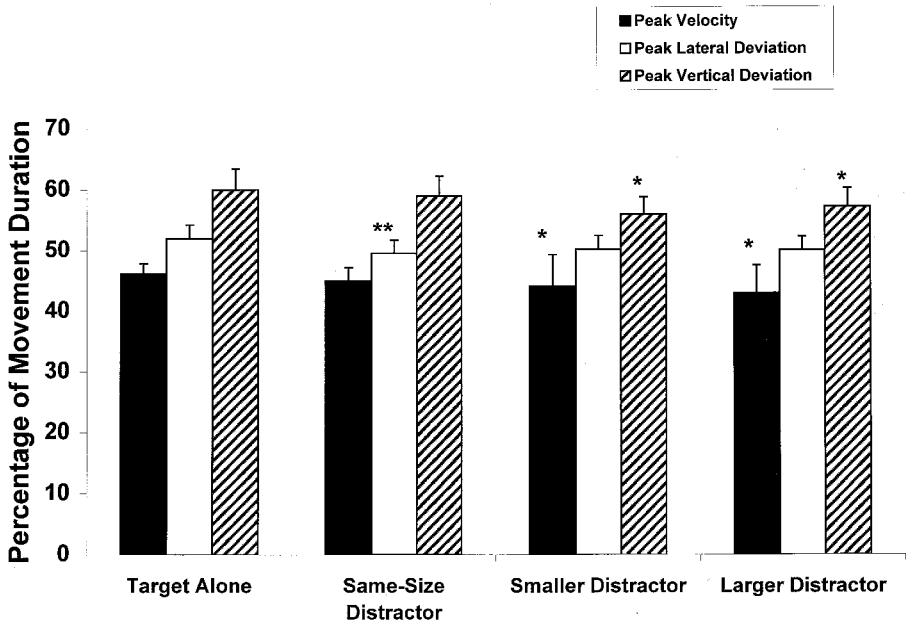


FIG. 2. Mean time to peak velocity, peak lateral deviation, and peak vertical deviation (+SE) as a percentage of movement duration for the target presented alone, or with a same-size distractor, smaller distractor, or larger distractor, in the constant vision, fast speed condition.

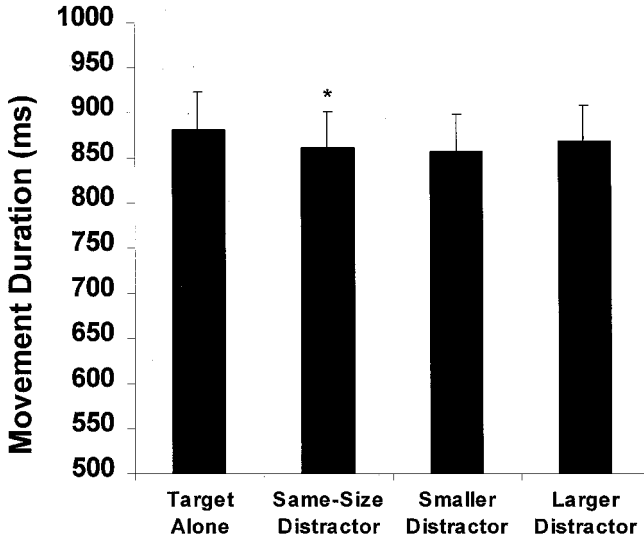


FIG. 3. Mean amplitude of movement duration (+SE) for the target presented alone, or with a same-size distractor, smaller distractor, or larger distractor, in the constant vision, fast speed condition.

Limited Vision, Fast Speed. Peak vertical deviation was attained significantly later when the target was accompanied by a distractor of the same size than when the target was presented alone (see Table 3).

Target Alone versus Target with Smaller Distractor

Constant Vision, Normal Speed. Peak velocity significantly increased when the target was accompanied by a small distractor compared with the target presented alone, $F(1, 9) = 10.43, p < .01$ (see Figure 4). As a percentage of movement duration, peak velocity and peak vertical deviation were attained significantly earlier when the target was accompanied by a small distractor than when the target was presented alone: Velocity, $F(1, 9) = 5.05, p < .05$; vertical deviation, $F(1, 9) = 7.28, p < .05$ (see Figure 2).

Target Alone versus Target with Larger Distractor

Constant Vision, Normal Speed. As a percentage of movement duration, peak velocity and peak vertical deviation were attained earlier when the target was accompanied by a larger distractor than when the target was presented alone: velocity, $F(1, 9) = 7.44, p < .05$; vertical deviation, $F(1, 9) = 5.35, p < .05$ (see Figure 2).

Constant Vision, Fast Speed. Peak grasp was attained significantly later when the target was accompanied by a large distractor than when the target was presented alone (see Table 3).

TABLE 3

Planned contrasts reaching significance, under the "constant vision, fast speed", "limited vision, normal speed" and "limited vision, fast speed" conditions in Experiment 1

		<i>Target Alone</i>	<i>Same-Size Distractor</i>	<i>F(1, 9)</i>	<i>Target Alone</i>	<i>Large Distractor</i>	<i>F(1, 9)</i>
constant vision, fast speed	peak grasp ^a				60.52 (3.39)	62.44 (3.49)	7.02*
limited vision, normal speed	peak grasp ^a				64.59 (4.52)	62.47 (3.56)	5.56*
limited vision, fast speed	peak velocity ^b				832.23 (145.03)	809.86 (138.56)	6.89*
	% time to peak lateral deviation				54.13 (4.68)	50.51 (6.50)	7.28*
	% time to peak vertical deviation	67.02 (12.45)	70.64 (13.79)	19.46**			

^aMm. ^bMm/s.

* $p < .05$ ** $p < .01$

Note: Values in parentheses are standard deviations.

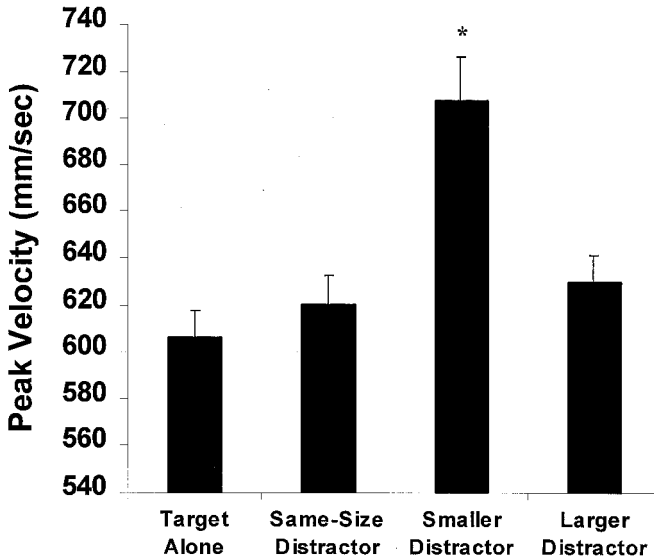


FIG. 4. Mean amplitude of peak velocity (+SE) for the target presented alone, or with a same-size distractor, smaller distractor, or larger distractor in the constant vision fast speed condition.

Limited Vision, Normal Speed. Peak grasp occurred significantly earlier when the target was flanked by a large distractor than when the target was presented alone (see Table 3).

Limited Vision, Fast Speed. Peak velocity was significantly decreased when the target was accompanied by a large distractor than when the target was presented alone (see Table 3). Moreover, as a percentage of movement duration, peak lateral deviation was attained significantly earlier when the target was accompanied by a large distractor than when the target was presented alone (see Table 3).

In summary, the presence of a distractor altered the expression of several crucial programming and execution reach-to-grasp parameters. Contrary to suggestions in the previous literature, the majority of alterations were observed under constant vision and normal speed of movement; in this case, only transport component parameters were affected. When the distractor was identical to the target, movement duration was reduced, and peak lateral deviation was reached earlier. When the distractor was different, peak velocity was altered. Moreover, as a percentage of movement duration, the attainment of these parameters, as well as peak velocity, peak vertical deviation, and peak lateral deviation, was hastened.

Discussion

In Experiment 1, participants reached for and picked up a midsagittal target, which was presented alone or was accompanied by a smaller, larger, or same-size distractor. Reaches were performed under two visual conditions—constant vision and limited vision—and under two speed conditions—normal speed and fast speed. Averaged across distractor presentation, and consistent with previous literature (Jackson et al., 1995; Wing, Turton, & Fraser, 1986), speed and vision had a generalized influence on kinematic parameters. In contrast to results of Tipper et al. (1997) and Jackson et al. (1995), however, the presence or size of distractors per se did not have an added impact.

The most consistent distractor interference effects were obtained under normal speed and constant vision conditions and when the distractor was of *different* size to that of the target. In this case, the duration of movement was unaltered but the amplitudes of peak velocity, acceleration, and deceleration increased and were attained earlier in the course of the movement. Conversely, trajectory parameters (the vector of the hand through space) were unaltered. This argues against the possibility that the kinematic changes were due to physical obstruction by the distractor.

From the pattern of results, it is evident that it is not merely the presence of a distractor that gives rise to interference, but specifically the presence of a distractor different in size from the target. The target itself never altered in terms of colour, dimensions, position, or direction, and there was no variation in the prehension requirements for each trial. Moreover, we discount the possibility that interference is attributable to encoding of the volumetric properties of the distractor (Tipper et al., 1997, 1998). If this were the case, interference would have been evident in the presence of the same-size distractor. We conclude that interference emerges when a feature of the distractor different from that of the target was encoded and processed. At this point, however, it is

difficult to postulate that the different size of the distractor evoked a different grasp programme that was suppressed, because, unlike transport, grasp parameters were not consistently altered. Peak grasp, for example, was not larger when the distractor was larger, or smaller when the distractor was smaller.

Size, however, is only one feature that may vary between stimuli. In Experiment 2, we manipulated a different feature, orientation. If interference effects do indeed result when distractor characteristics different from those of the target are processed, then the same pattern of interference should be obtained when the orientation of the distractor is different from that of the target.

EXPERIMENT 2

In Experiment 1 we showed that a distractor of different size from the target gave rise to interference effects in the reach-to-grasp movement. We postulated that a similar pattern of interference would be evident if target and distractor were to vary in characteristics other than size. We chose to vary the orientation of the distractor because of evidence that neurones of the primate posterior parietal cortex (Area 7) respond to orientation stimuli to be grasped (Taira et al., 1990). Furthermore, the neurones of the posterior parietal cortex may be involved in forming and shaping of grasp (for example, Rizzolatti et al., 1988). They are part of the dorsal visual pathway controlling the adjustment of hand movements towards objects in the reaching space (Goodale & Milner, 1992). Overall, the evidence suggests that the orientation of stimuli is an important factor in prehension.

The issue of object orientation adds a third level of complexity. Grasp orientation, as well as transport and grasp aperture parameters, requires consideration. This is because the location and orientation of objects in space specifies the final posture of the arm, wrist, and fingers (see, e.g. Flanders & Soechting, 1995). Indeed, prehension may consist of three visuomotor channels: transport, grasp, and grasp orientation (Arbib, 1981; Desmurget et al., 1996; Jeannerod, 1988, 1992). We know that grasp orientation is sensitive to object orientation (Desmurget et al., 1996). Thus, if distractors are presented in an orientation different from that of the target, any potential interference may manifest in measures of grasp orientation.

Based on the results of Experiment 1, we expect that interference effects will be particularly marked with distractors presented at a different orientation from that of the target. Specifically, trajectories of the hand should be more curved with the slanted distractors than with upright distractors, manifesting as higher values for lateral and vertical deviations (Tipper et al., 1997). We hypothesize that movement duration and peak velocity, as well as the temporal measures (time to peak velocity and time to peak lateral and vertical deviation), will alter when in the presence of a slanted distractor compared with the target presented alone. However, due to differences in paradigm (between Experiment 1 of this study and previous work) we do not speculate on the direction of alteration. We also calculate grasp orientation angles and hypothesize that they will be greater in the presence of the slanted than the upright distractors. Finally, because the size of target and distractors is always the same, and to avoid reporting an excessive number of parameters and therefore comparisons, we do not report on grasp aperture or time to peak grasp.

Method

We recruited eight normal healthy participants (four females, four males; mean age 23.75 years, $SD = 4.17$). All were right-handed and had normal or corrected-to-normal vision.

Apparatus, Materials and Procedure

The experimental apparatus, recording techniques, initial hand positions, and instructions were the same as those in Experiment 1. The target was a red wooden cylinder (length 10 cm, diameter 1.2 cm) fixed to the centre of a wooden base ($8.5 \times 6.5 \times 0.5$ cm) presented either alone or flanked by a distractor. There were two types of distractors. The first was identical to the target and presented such that its centre was 30 cm from the starting switch and 20° to the right or left of the target. The second type of distractor was a cylinder (length 12 cm, diameter 1.2 cm) slanted at a 45° angle on its base, such that its height was the same as the height of the target. It was positioned such that its gravitational centre was 30 cm from the starting switch and 20° to the right or left of the target, and it pointed either towards the subject along the midsagittal plane or 45° away from the midsagittal plane.

Prehension movements were recorded under two visual conditions, constant vision and limited vision, as described in Experiment 1.

Dependent Variables, Data Analysis, and Design

Apart from grasp parameters, we generated and analysed the same dependent variables as those described in Experiment 1. We included two parameters of grasp orientation, according to descriptions of object-based frame of reference calculations by Paulignan, Frak, Toni, and Jeannerod (1997). A hypothetical straight line (opposition axis) was drawn between the thumb and index markers at the end of movement. The angular deviation of this line from the object-centred XY (horizontal) reference axis and YZ (vertical) reference axis were calculated (grasp XY orientation and grasp YZ orientation, respectively). Values falling to the right of the reference axes were assigned a positive sign; values falling to the left of the reference axes were assigned a negative sign.

Each reaching condition was administered as a block of 40 trials, randomized and counterbalanced as in Experiment 1.

All constant vision trials were compared with limited vision trials, averaged across distractor presence. For each visual condition, three planned contrasts were conducted. Each type of distractor presentation (“target plus upright distractor”, “target plus forward distractor”, “target plus outward distractor”) was averaged and compared with “target alone”. Only the contrasts that reached significance are reported for each parameter.

Results

Orientation of the distractor affected prehension parameters in an entirely different manner from that of size (see Tables 4 and 5). Comparisons tended to be significant in limited vision conditions. Moreover, the few significant effects were evident in both amplitude and trajectory parameters. It should be noted that the effects, although significant, are weakly so. Overall, when pre-viewing of the stimuli was not possible, peak

TABLE 4
Distractor orientation: The influence of visual availability on prehension parameters for Experiment 2

	<i>Constant Vision</i>	<i>Limited Vision</i>	<i>F(1, 7)</i>
movement duration ^a	968.78 (146.19)	1041.09 (196.64)	2.59
peak velocity ^b	500.85 (94.64)	469.65 (94.81)	4.16
% time to peak velocity	47.08 (4.11)	49.44 (5.78)	1.67
peak lateral deviation ^c	17.49 (4.89)	19.31 (9.54)	0.59
% time to peak lateral deviation	48.74 (4.64)	50.85 (6.19)	0.79
peak vertical deviation ^c	59.79 (11.93)	64.78 (13.01)	11.63**
% time to peak vertical deviation	69.39 (14.41)	69.09 (15.31)	0.01
grasp XY orientation ^d	48.01 (46.64)	29.07 (44.68)	2.008
grasp XZ orientation ^d	2.08 (18.87)	-3.72 (18.79)	3.294

^aMsec. ^bMm/sec. ^cMm. ^dDegrees.

** $p < .01$

Note: Values in parentheses are standard deviations.

TABLE 5
Planned contrasts reaching significance for the "constant vision" and "limited vision" conditions for Experiment 2.

	<i>Target Alone</i>	<i>Upright Distractor</i>	<i>F(1, 7)</i>	<i>Target Alone</i>	<i>Forward-Slanted Distractor</i>	<i>F(1, 7)</i>
Constant vision	peak vertical deviation ^a	58.09 (12.57)	60.99 (12.69)	8.58*		
Limited vision	peak velocity ^b			476.30 (96.27)	466.81 (94.18)	5.61*
	peak vertical deviation ^a	65.35 (14.58)	62.76 (14.27)	5.82*		
	% time to peak lateral deviation			52.23 (6.52)	50.06 (5.15)	8.09*

^aMm. ^bMm/sec.

* $p < .05$

Note: Values in parentheses are standard deviations.

velocity was lower, and the lateral deviation of the trajectory of the hand, although not altered, was attained significantly later in the presence of forward-slanted distractors. The forward- and outward-slanted distractors, conversely, did not cause marked alterations in the expression of kinematic parameters. Interestingly, no differences were evident in grasp orientation. This was probably due to large between-subject variability in grasp orientation (see, for example, *SDs* in Tables 4 and 5).

Discussion

In Experiment 2, participants were instructed to reach for and pick up a target (a wooden cylinder) placed midsagittally. The target was presented alone or accompanied by a distractor. The distractor was one of the following: upright and identical to the target; oriented at a 45° angle to the target and slanted forward, parallel to the midsagittal plane; or oriented at a 45° angle to the target and slanted 45° away from the midsagittal plane. Reaches were performed under two visual conditions, constant vision and limited vision.

Although distractors of a different orientation from that of the target had some impact on prehension, the pattern of influence differed from Experiment 1 in three main ways. First, averaged across distractor presentation, limited vision did not disrupt prehension consistently, compared with constant vision. Second, all but one of the significant comparisons of kinematic parameters was evident under limited vision conditions, and the effect sizes were small. Third, few prehension parameters were disrupted by the presence of distractors: Peak velocity decreased and peak lateral deviation attained earlier. Peak vertical deviation was significantly lower in the presence of a distractor identical to the target. Overall, however, predictions regarding lateral and vertical trajectory deviations, grasp orientation, or advancement of temporal parameters were not supported.

Some alterations in prehension parameters were evident as a result of the presence of distractors. Because these alterations were mostly evident during limited vision, and when the distractor encroached maximally on the reaching space (forward-slanted), we argue for the more parsimonious interpretation of physical obstruction by the distractor rather than perception and processing of its orientation. This is supported by the seeming lack of influence of distractor orientation on the orientation of the grasp, in either the XY or the YZ plane.

To place the findings in the context proposed by Tipper et al. (1997, 1998), volumetric properties of distractors resulted in interference, but only when they impinged on a certain amount of reaching space. Conversely, we showed that prior knowledge of the stimuli is indeed an important factor: Alterations were most frequent under limited vision conditions.

GENERAL DISCUSSION

To summarize the paradigm used in this series of studies, participants reached for a midsagittally placed target, which was presented either alone or in the presence of a distractor. In Experiment 1, the distractor was the same size as the target, larger, or smaller. In Experiment 2 the distractor was the same or different orientation as the target. Speed of movement execution was manipulated (Experiment 1), as was vision (Experiments 1 and 2).

Contrary to previous suggestions in the literature (Howard & Tipper, 1997; Tipper et al., 1997), speed of movement did not contribute specifically to interference effects in the presence of distractors. Limited vision also had a generalized effect on prehension but little direct influence on interference effects, when either size (Experiment 1) or orientation (Experiment 2) of the distractor was varied.

Interference effects were evident most convincingly when the size of the distractor was manipulated under constant vision conditions. The presence of a different-size distractor increased peak velocity. Moreover, this parameter and also peak vertical deviation were attained earlier during the movement phase. Conversely, the presence of a distractor that was different in orientation from that of the target did not alter movement parameters under constant vision conditions. When viewing of the objects was not possible prior to movement initiation, peak velocity decreased, peak vertical deviation increased, and attainment of peak lateral deviation was delayed.

Here we may return briefly to the issue of parameters showing the influence of interference. The few parameters showing alterations in Experiment 2, although under different visual conditions, were the same as those in Experiment 1. Aside from distractor features (size and orientation), the paradigms of Experiments 1 and 2 were identical. We therefore re-assert our speculation that the set of parameters manifesting interference due to distractors depends on the paradigm implemented.

The crucial point to emerge from this series of experiments is that distractor features are processed even though they are irrelevant to the goal. Thus far, this speculation fits well in the context of current studies of perceptual processing. It echoes the model proposed by Tipper et al. (1997) of processing of parallel perceptual inputs.

Our findings, however, add a level of complexity to previous descriptions. In the first place, the impact of irrelevant perceptual inputs on the expression of prehension parameters is seen when the intrinsic features of the distractor *differ* from those of the target. Second, not all object features have the same impact: Size and orientation were not equally disruptive. Therefore, it is not merely the putative perceptual analysis process that causes interference. We argue that when distractor and target features differ, more complex analyses are involved. There are at least two possibilities. One, as suggested by Tipper and colleagues (Howard & Tipper, 1997; Tipper et al., 1997), is that a competing response from a separate neuronal population is evoked, which needs to be suppressed. Another possibility is that when target and distractor features differ, perceptual processing is more demanding of time and resources (Allport, 1987; Duncan, 1996; Neumann, 1987).

It is difficult to reconcile the current findings with the model of competing responses in neuronal populations. There is evidence for preferential neuronal activation to size, shape, colour, and orientation of an object (Rizzolatti et al., 1988; Rizzolatti et al., 1987; Sakata, Taira, Kusunoki, Murata, & Tanaka, 1997; Shikata, Tanaka, Nakamura, Taira, & Sakata, 1996). To our knowledge, however, there is no clear evidence of population-level activation to these features. Nor is there clear evidence of activation of two distinct populations in the presence of target and distractor, which may justify the postulation of competition between neuronal populations. Moreover, these neuronal populations fall along the “dorsal” visual stream (Goodale & Milner, 1992; Sakata et al., 1997; Ungerleider & Mishkin, 1982), which codes for visually guided action. On a physiological basis, therefore, size and orientation of the distractor should have had a comparable impact on the expression of prehension parameters to the target. This, however, was not the case: Size of the distractor markedly altered prehension, but the influence of its orientation was not as convincing.

We argue that evidence from neuronal activation has provided a good foundation for speculation about visually guided action. We know, for example, that cortical areas as well as the basal ganglia are involved in coding of sensory information to result in a coherent motor programme (Keele, 1981). There are processes beyond this level, however, which remain unclear. How are sensory inputs organized and relevant features of the stimulus array separated from non-relevant features? How does this organization translate into successful planning and execution of a motor programme? Some possibilities about this process have been broached in the cognitive literature.

The models proposed by Allport (1987) and Neumann (1987) make specific predictions about interference effects in prehension. The foundation of the models is that all incoming information is processed at an early stage (see, e.g. Broadbent, 1971). Thereafter, parallel streams of information about the object (i.e. shape, size, colour, and position) are linked together, and de-coupled from similar information about other objects. It is at this point that favoured or relevant information is given priority, and non-relevant information is suppressed. Therefore these models would predict maximal interference when there is more information to be processed and organized—that is, when the distractor is different from the target. This was, in fact, seen in Experiment 1: Some alterations were seen in movement duration and the lateral deviation of the hand's trajectory when the distractor was identical to the target but by default in a different location. The greatest impact of a distractor, however, was seen when it was in a different location and also of a different size.

A similar conclusion may be reached by applying the integrated competition model (Duncan, 1996; Duncan, Humphreys, & Ward, 1997). Comparable to the postulation that all incoming information undergoes some early-stage processing (Allport, 1987; Neumann, 1987), Duncan and colleagues suggest that multiple brain systems are activated by visual input. This input is processed to some degree: Different brain systems responsive to features of the same object integrate such that the "winning" object dominates, whereas systems responsive to features of a different object compete, resulting in interference. The "winning" or relevant object features are specified by top-down neural priming. In the present study, the relevant features were those of the midsagittally placed cylinder. In other words, whereas relevant or target features dominate in the formulation of action, non-relevant features in an array are also processed and cause interference. Therefore, the more non-relevant information there is to be processed, the greater the interference (Bonfiglioli & Castiello, 1998; Castiello, 1996).

Although these models describe the processing and organization of sensory inputs in visually guided action, the differential impact of size and orientation still requires explanation. We speculate that it is not so much size or orientation that is crucial, but rather whether the distractor is the same as or different from the target. In an intact system, an object is recognized regardless of orientation (e.g. Farah, 1990). In Experiment 1, the distractor was not the same object as the target when it was larger or smaller. In Experiment 2, however, regardless of orientation, the distractor was arguably the same as the target.

A final issue requires consideration. In a paradigm involving repeated identical reaches, it may be argued that the coupling, linking, and organization (Allport, 1987) or object dominance across systems (Duncan, 1996; Duncan et al., 1997) would be

completed during the practice trials. Based on these models, therefore, lack of interference might be predicted. In this series of experiments, however, interference effects were manifest even though the reach requirements were identical in each trial. We speculate that the system resets itself after every reach, thereby necessitating perceptual processing, attention coupling and integration of information at the commencement of every reach. This is consistent with proposals by Goodale and colleagues (Goodale, 1998; Goodale, Jakobson, & Keillor, 1994) that the dorsal stream of the visual pathway is responsible for instantaneous, on-line visuomotor computations, which do not depend on previous experience. Although there are obvious disadvantages to this in terms of efficiency in planning, processing, and programming, the advantage is flexibility. New and potentially important information is not missed, and maladaptive perseverative responses can be inhibited. Indeed self-inhibition of responses is an integral part of motor behaviour. Simone and Baylis (1997) demonstrated poor inhibition of responses in the presence of distractors in patients with Alzheimer's disease. In the clinical setting, poor inhibition of unwanted or inappropriate responses towards environmental stimuli is termed "utilization behaviour" (Lhermitte, 1983).

In conclusion, this study qualifies and expands previous literature. The findings of this series of experiments fall into two categories. First, although vision and speed of movement execution were important factors in prehension, the number of comparisons indicating distractor interference effects were not more numerous in the limited vision and fast speed conditions than in constant vision and normal speed conditions. Second, features of task-irrelevant distractors altered the expression of prehension parameters. This was evident most convincingly when the size of the distractor was different from that of the target, and less so when the orientation of the distractor was manipulated.

We argue that the findings are consistent with both physiological and attention models of action-related object processing.

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