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Grasping a Fruit: Selection for Action

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This study used a natural task, with no emphasis placed on speeded responses, to investigate unconscious information processing. Using the ELITE system, a kinematic analysis was performed of the upper limb reach-to-grasp movement. Nine experiments explored how the presence of distractors affects the transport and grasp component of this movement. Experiment 1 showed that the kinematics for grasping apples, mandarins, cherries, and bananas were measurably different. Experiments 2A–D, 3, and 4 showed that these kinematics were not affected by the presence of nearby distractor fruits of either the same or a different kind. In Experiment 5, interference effects became evident when participants were required to perform a subsidiary task involving the distractor (counting the number of times a laterally placed fruit was illuminated). Experiment 6, requiring both grasping a target fruit and counting the number of times that this fruit was illuminated, revealed no interference effects. Taken together, these results suggest that selection for action does not involve substantial passive processing of distractors. However, dual-action processing of simultaneously presented objects does appear to involve automatic processing of even the task-irrelevant properties of the distractor.

How does the central nervous system direct attention to one object among several and generate the limb movements necessary to grasp and manipulate this selected object? In a typical visual scene, many objects of different shapes, colors, and textures impinge on the retina. People cannot make an eye or a limb movement to all of these objects at any one moment. It is also presumably difficult to specifically attend to more than one or two relevant objects at a time. Much unwanted information must be processed. The first stage in this processing is the figure–ground segmentation, where, in a largely automatic manner, figures are distinguished from their background (Baylis & Driver, 1993). However, even after operation of this segmentation, the visual scene remains very complex because of its many different figures. Thus, a second stage of object feature selection is necessary. Attention is thought to operate at this second stage, selecting one or two objects at a time (Wise & Desimone, 1988). This operation of selecting part of simultaneous sources of information, by enhancing the processing of some objects, suppressing information from others, or both, is traditionally referred to as selective attention (Johnston & Dark, 1986; for a review, see Theeuwes, 1993). Of course, this does not mean that this is the only possible role of attention. Indeed, in order to minimize response-interference effects, it has been proposed that information about irrelevant stimuli, possibly including information for potential motor programs that interact with these stimuli, should be effectively decoupled or isolated from the control of particular actions (Allport, 1980, 1987, 1989, 1993). In any case, it is clearly difficult to establish whether or what kind of processing of irrelevant stimuli occurs.

Allport (1987) defined one aspect of the selective integration problem as "selection-for-action." For example, when a person is choosing a piece of fruit from a bowl, many fruits are visible and within the reaching space, but only the one that the person would like to pick up governs the particular pattern and direction of movement. How is the motor output for reaching and grasping that particular fruit selected? Where is the locus of this selection? Is selection at an early or a late stage of processing (e.g., Bundesen, 1990; Duncan, 1987; Johnston & Dark, 1986; Kahneman & Treisman, 1984)? Do the other fruits, different in size, shape, color, and weight, produce interference? Is there a role played by selective attention in coding all characteristics of the correct grasping module? Perhaps there is a central attentional system that supports the entire computation (Norman & Shallice, 1986). Alternatively, attentional functions may be of many different kinds, serving a large range of different motor computational purposes (Allport, 1993).

Recently, Tipper, Lortie, and Baylis (1992) suggested that for an action such as selective reaching to a target with nearby distractors, attention accesses an action-centered internal representation. They found significant interference only if the distractor was on or near the hand trajectory to the target. It was as if such distractors acted as potential obstacles when the target was being reached for. Tipper et al. (1992) proposed that because the distractors cannot be

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excluded from the computation, "motor programs for the distractors are also specified in parallel" (p. 903) and that this produces interference effects of which we are rarely aware. Such a view suggests that the brain must often consider multiple, simultaneous, and conflicting motor signals before it is able to execute the correct program for a determined target stimulus (Goldberg & Segraves, 1987). The first aim of the present study was to determine at what point attentional mechanisms act for motor output selection. For example, they may act before movement initiation to exclude a priori the competing object and distractor motor outputs. Alternatively, the effect of competition between the target object and the distractors may be inevitable and constant. From the computational point of view, this could lead to kinematic modifications of the motor output required for the reach to grasp a specific object interspersed among others. In other words, if there is an attentional process in choosing the correct motor output, then experimental manipulations that influence selective attention (e.g., set size) might also influence movement kinematics.

The current study used six main experiments to explore the mechanisms of selection-for-action planning and execution. Distractor techniques were used, and visuospatial attentional modules were manipulated. In the first four experiments, null effects were found; that is, no interference occurred with the presentation of distractor objects. However, the positive results that emerged in Experiment 5, as opposed to those in Experiment 6, indicate that covert attentional mechanisms appear to be relevant for object-related motor output selection.

Experiment 1

Jeannerod (1981, 1984) described two main components for the reach-to-grasp movement. The transport component is the reaching movement required to bring the hand to the object to be grasped. The manipulation component is the movement required to grasp the object for such functions as manipulation, identification, and use. Previous studies (Castiello, Bennett, & Mucignat, 1993; Castiello, Bennett, & Paulignan, 1992; Castiello, Bennett, & Stelmach, 1993; Castiello & Jeannerod, 1991; Gentilucci et al., 1991) have already demonstrated that the kinematics of both of these components change according to the type of grasp adopted. These differences were found with a comparison between precision grip and whole-hand prehension.

Many authors (Allport, 1987, 1993; Neumann, 1987; Wise & Desimone, 1988) have used the example of picking up an apple to speculate about how selection mechanisms allow parameterization for grasping a certain fruit that is positioned among others. The aim of the current experiment was to provide baseline kinematic data for the reach to grasp of an apple as well as of different fruits. Participants were asked to reach out and grasp an apple, a mandarin, a cherry, or a banana. The use of a variety of fruits, and thus of a variety of grasps, allowed a more complete description of the kinematic changes and selection according to grasp type. For example, the grasp used for a banana is clearly different from that used for an apple. Differences at the kinematic level can be used as a parameterization index of selection for action. This allows kinematic comparisons across experiments and thus of the interference effects produced when other fruits or distractors are presented (Experiments 2–6).

Method

Participants

Eight students (4 women and 4 men, aged 18–32 years) volunteered to participate in this experiment. All were right-handed according to the Edinburgh Inventory (Oldfield, 1971), reported normal or corrected-to-normal vision, and were unaware of the purpose of the experiment. Each participant attended one experimental session of approximately 0.5-hr duration.

Apparatus and Materials

The experiment was conducted under normal lighting conditions. Details of the experimental setup are shown in Figure 1. The participant was seated in front of the table working surface (1 m × 1 m). Prior to each trial, the participant placed his or her right hand on the table in the midsagittal plane, 15 cm from the thorax. In this position, the shoulder was flexed (5–10°), the elbow was flexed, the forearm was semipronated, and the wrist was in 10–15° of extension. The index finger and the thumb were held gently opposed, and the ulnar border of the hand rested on a pressure-sensitive starting switch. A single piece of fruit (apple, mandarin, cherry, or banana) was presented on a tray so that the fruit was 30 cm from the starting position. The position of the fruit was central (midsagittal plane), ipsilateral (20° to the right of the central fruit), or contralateral (20° to the left of the central fruit). The alignment of these fruits is shown in Figure 2A. Each fruit could be gently highlighted by a spotlight positioned 1.8 m above the table. Except for the single piece of target fruit, no other fruits were positioned upon the working surface. The order of presentation according to type of fruit and its position was counterbalanced across participants. The fruit was present, and thus visible to the participants, for at least 10 s prior to trial onset.

Reflective passive markers (0.25 cm in diameter) were attached to the following points of the reaching limb: (a) wrist—radial aspect of the distal styloid process of the radius, (b) index finger—radial side of the nail, and (c) thumb—ulnar side of the nail. Movements were recorded with the ELITE system (Ferrigno & Pedotti, 1985). This system consisted of two infrared cameras (sampling rate 100 Hz) inclined at an angle of 30° to the vertical and placed 3 m in front of the table and 3 m apart. The calibrated working space was a parallelpiped (60 cm long × 30 cm wide × 60 cm high) from which the spatial error measured from stationary and moving stimuli was 0.04 mm. Calibration was performed using a grid of 25 markers (5 × 5). The centroid of each marker was placed 15 cm from that of another. Using the procedure of Haggard and Wing (1990; see also Wing, 1993), the mean length of a bar with two markers attached 15 cm apart, as reconstructed from the ELITE data, was 14.70 cm (*SD* = 0.22 cm). Coordinates of the markers were reconstructed with an accuracy of $^{1}/_{3,000}$ over the field of view and sent to a host computer (PC 386). The standard deviation of the reconstruction error was $^{1}/_{3,000}$ for the vertical (*Y*) axis and $^{1.4}/_{3,000}$ for the two horizontal (*X* and *Z*) axes.

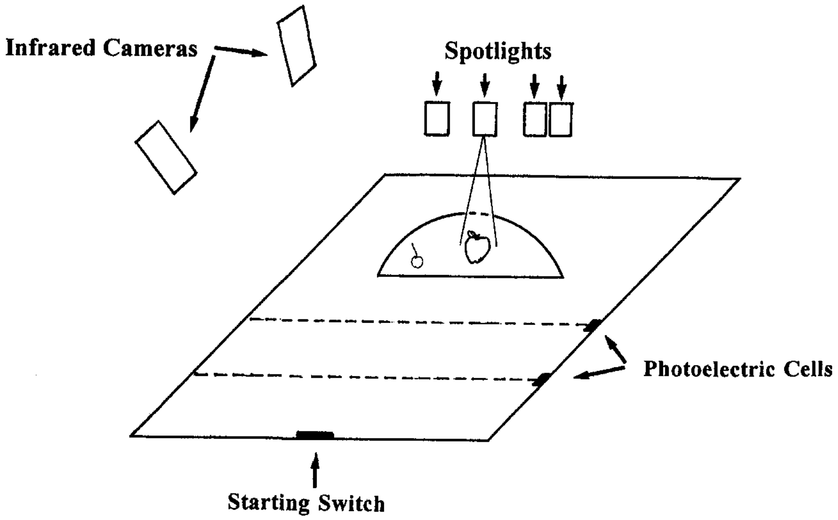

Figure 1. Details of the experimental setup.

Procedure

A warning signal (880 Hz; duration of 250 ms) was given at a randomized time from 500 to 2,000 ms prior to highlighting of the fruit; this variability was to reduce expectancy effects. As soon as the fruit was highlighted, the participant was required to reach, grasp the fruit, and bring it to the starting position. In order to promote a natural movement, no instructions were given as to the speed of responding to illumination, the velocity of movement, or the type of grasp to adopt. Each participant performed 5 practice trials in the same manner as the subsequent block of 10 trials for each fruit type. In both the practice and experimental trials, all participants used grasp types that changed according to the fruit. A whole-hand prehension involving all digits and the palm was used to grasp the apple. A small whole-hand prehension, whereby there was not as much contact with the palm, was used for the mandarin. A precision grip between the index finger and the thumb was used to grasp the cherry, and a clench-type grasp, whereby the fingers hooked the fruit in opposition to the thumb, was used for the banana.

Data Processing

The ELITE processing package was used to assess the data. This gave a three-dimensional reconstruction of the marker positions. The data were then filtered using a FIR linear filter with a transition band of 1 Hz (sharpening factor = 2; D'Amico & Ferrigno, 1990, 1992). The transport component was assessed by analyzing the trajectory, the velocity, and the acceleration of the wrist marker. The manipulation component was assessed by analyzing the trajectory of each of the hand markers and the distance between these two markers. The velocity of the opening and closing of the digits was also assessed. Movement initiation time, so-called because no emphasis was placed on making a rapid response, was taken from release of the starting switch. The end of the movement was taken as the time when the fingers closed on the fruit and there was no further change in the distance between the index finger and the thumb. The period following the end of the movement, whereby the fruit was brought to the starting position, was not assessed. The dependent variables were initiation time; movement duration; for the transport component the times to peak velocity, peak acceleration, and peak deceleration of the wrist marker and the amplitudes of these peaks (amplitude peak velocity, amplitude peak acceleration, and amplitude peak deceleration, respectively); and for the manipulation component, the times to peak grip aperture and peak grip velocity, the amplitudes of the aperture and velocity peaks, and specification of the index finger for precision grip (specification time). This latter parameter refers to the time at which the index finger deviates from the more ulnar digits for specification of precision grip (break detection algorithm; Castiello, Bennett, & Stelmach, 1993).

Results and Discussion

The means for each of these variables were determined for each block of trials. In order to compare kinematic temporal data of this experiment with those of the following experiments, each temporal value was also calculated as a percentage of movement duration. These data were analyzed using an analysis of variance (ANOVA) whereby the within-group variables were type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension) and position (central, ipsilateral, or contralateral). Where necessary, significant effects were further assessed using the Newman–Keuls test for pairwise comparisons between means (5% significance level). Regression analyses were used to determine correlations between temporal events of the manipulation and transport components. The Fisher's Z transformation of data was used for homogeneity of variance and to counteract any nonnormal distributions.

Absolute and, where relevant, relative values are reported in Table 1. Given the simplicity of the task, performance errors when reaching to grasp the fruits, such as an incorrect homing phase or missing the target, were rare (<1%) and were not analyzed. The pattern of results obtained for initiation time and for both the transport and manipulation components resembled that of other reach-to-grasp movement studies (Jeannerod, 1981, 1984) and that of more

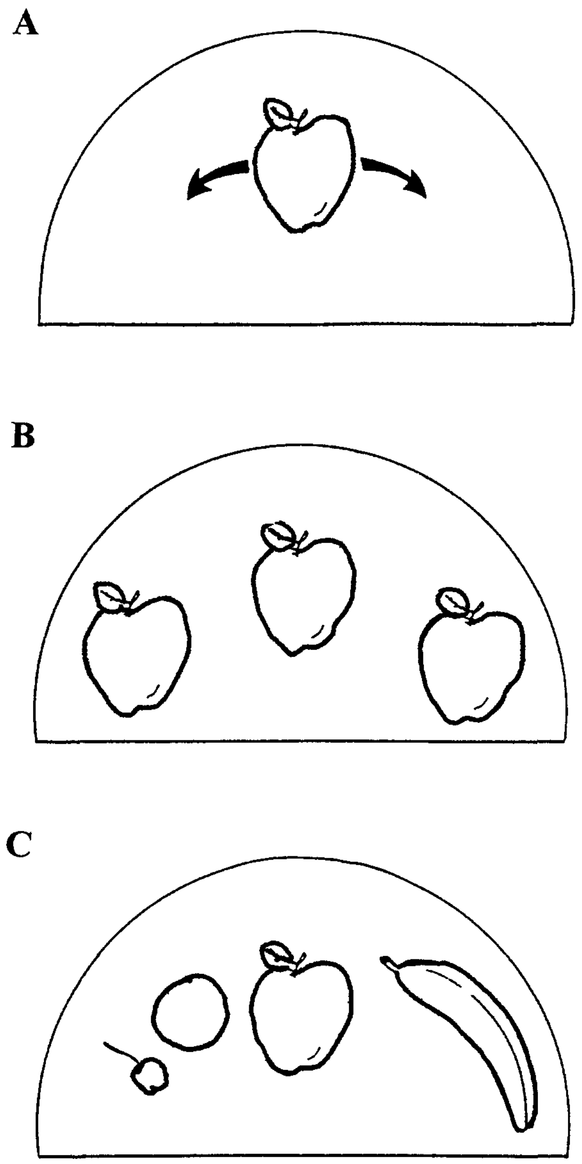

Figure 2. A: Example of the position of the fruit in Experiment 1. Arrows indicate that the fruit could also be positioned on the right or the left of the tray. B: Example of the positions of the fruits in Experiment 2A for the compatible distractor condition. C: Example of the positions of the fruits in Experiment 2A for the incompatible distractor condition.

recent studies in which different types of grasp were used (Castiello, Bennett, & Mucignat, 1993; Castiello et al., 1992; Castiello, Bennett, & Stelmach, 1993; Gentilucci et al., 1991). Initiation time did not change according to fruit type. Movement duration was longer when participants were reaching for the cherry (precision grip) than when they were reaching for the apple (whole-hand prehension), and the values for the reach to grasp of the mandarin and the banana were intermediate, $F(3, 21) = 43.54$, $p < .0001$. That is, the movement was longest for the smallest fruit. For the transport component (see Figure 3), the velocity curves were consistently bell-shaped. The peak of this profile was reached at approximately 40% of the movement, and the duration of the deceleration phase (from peak velocity to the end of the movement) was related to the type of grasp adopted. This phase was longest for the cherry (precision grip), and it showed progressively decreasing values for the mandarin (small whole-hand prehension), the banana (clench), and the apple (whole-hand prehension), respectively: absolute $F(3, 21) = 31.04$, $p < .0001$, and relative $F(3, 21) = 28.02$, $p < .0001$. The times of wrist peak acceleration and deceleration were approximately 26% and 61% of the movement, respectively, and showed no differences according to fruit type. However, the amplitudes of the velocity, acceleration, and deceleration peaks were all greater for the apple (whole-hand prehension) than for the other fruits: $F(3, 21) = 22.04$, $p < .0001$ for amplitude peak velocity; $F(3, 21) = 18.03$, $p < .0001$ for amplitude peak acceleration; and $F(3, 21) = 18.06$, $p < .001$ for amplitude peak deceleration (see Figure 3). These results for the transport component are consistent with those from previous studies (Castiello, Bennett, & Mucignat, 1993; Castiello et al., 1992; Castiello, Bennett, & Stelmach, 1993; Gentilucci et al., 1991; Jeannerod, 1981, 1984; Marteniuk, Leavitt, MacKenzie, & Athenes, 1990). The length of the deceleration phase is generally related to accuracy and precision requirements of the task. Therefore, it was not unexpected that this phase would be longest for the fruit (cherry) that required a more precise grasp. Similarly, speed of movement generally shows an inverse relationship to task precision. Thus, movement velocity was greatest for the fruit requiring the more gross grasp (apple).

The position variable showed no significant effects; that is, apart from direction differences, the kinematics did not change according to whether the fruit was placed centrally, ipsilaterally, or contralaterally. In particular, movement duration showed no difference according to the ipsilateral–contralateral position. This result is not in accordance with those of Fisk and Goodale (1985), who found that reaching to ipsilaterally placed objects tended to be faster than reaching to contralaterally placed objects. However, invariance of movement duration has previously been observed for complex movements executed without enforced time constraints. Viviani and Terzuolo (1980), for instance, showed that writing the same letter at different sizes was achieved by simply changing the tangential velocity of the writing movement without changing its duration. Prehension movements such as those studied here and by Jeannerod (1984) appear to belong to this category.

The results for the manipulation component were in accordance with those from previous studies of reaching to grasp objects of different sizes (see Figure 3). Peak grip aperture was earlier for the more precise grasps: absolute $F(3, 21) = 28.16$, $p < .001$, and relative $F(3, 21) = 22.13$, $p < .001$. It occurred, for example, at 52% and 63% of movement duration for the cherry (precision grip) and the apple (whole-hand prehension), respectively. The amplitude of maximum grip aperture was also directly related to fruit size, being greater for the apple than for the banana, the mandarin, and the cherry, respectively, $F(3, 21) = 77.14$,

Table 1

Initiation Times, Movement Durations, and Kinematic Values (Absolute and Relative) for the Different Types of Fruit in Experiment 1

	Apple		Banana		Mandarin		Cherry	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	380	31	390	38	391	35	387	40
Movement duration (ms)	740	80	784	81	764	83	825	94
Transport component								
Time to peak velocity (ms)	302	27	312	33	309	27	320	29
%	41	5	40	5	40	3	39	4
Time to peak acceleration (ms)	193	21	213	27	201	19	218	25
%	26	2	27	1	26	3	26	3
Time to peak deceleration (ms)	452	51	471	49	448	50	512	52
%	61	5	60	7	59	7	62	9
Deceleration time (ms)	438	48	472	50	455	49	505	52
%	59	6	60	7	59	6	61	7
Amplitude peak velocity (mm/s)	753	88	728	75	703	74	672	69
Amplitude peak acceleration (mm/s^2)	7,124	840	7,088	712	6,918	712	6,425	650
Amplitude peak deceleration (mm/s^2)	6,845	732	6,669	680	6,728	812	6,112	784
Manipulation component								
Specification time (ms)							224	28
%							27	3
Time to maximum grip aperture (ms)	470	50	458	48	467	53	435	44
%	63	6	59	6	59	6	52	5
Amplitude grip aperture (mm)	110	5	74	7	68	7	55	6

$p < .0001$. For 5 of the 8 participants, significant positive correlations were found between the time to peak grip aperture and the time to peak deceleration ($ps < .05$). Again, this finding fits with previous results of temporal couplings between the transport and manipulation components. Note that previous studies have demonstrated that this coupling is flexible (Castiello, Bennett, & Stelmach, 1993). It may or may not be present for different participants, and it also shows variability according to the reach-to-grasp task performed by a given participant.

Experiment 2A

The results from Experiment 1 indicate that the kinematics of the reach-to-grasp movement change according to the dimension and the shape of the fruit. In this second experiment, the influence of interference effects (W. O. Shaffer & LaBerge, 1979; Stroop, 1935; Underwood, 1976) on these different movement kinematics was investigated by presenting the participant not only with the fruit that should be grasped but also with fruits in the immediate vicinity. Tipper et al. (1992) previously suggested that competing distractors appear to be analyzed to at least a semantic level and that there is a consequent effect on the computation of related motor programs (Keele, 1981). This line of reasoning suggests that the presence of distractor fruits within the work space should add to the computational difficulty with resultant effects on movement kinematics. Experiment 2A investigated such interference effects in two ways. In one, participants were required to grasp a piece of fruit presented on a tray with other fruits of the same type. For example, an apple was presented with other apples. Thus, competition effects on kinematics should emerge only with respect to the location of the fruit rather than with respect to the choice of a reach-to-grasp movement pattern. In the second mode for assessing interference effects, the fruit to be grasped was presented among fruits that differed in color, shape, and size. For example, an apple was presented with a banana. It could be postulated that the interference effects in this case would differ from those whereby all fruits were the same. Experiment 1 demonstrated that each fruit in the visual field requires its own specific kinematic patterning. The additional computations involved for selecting only one from these different patternings could result in interference effects on the finally executed motor output for the target fruit.

Method

Participants

Eight students (4 women and 4 men, aged 22–30 years) volunteered to participate; none had participated in Experiment 1. They showed the same general characteristics as the participants in Experiment 1. Each participant attended one experimental session of 1-hr duration.

Apparatus and Materials

The apparatus and the materials were the same as those described in Experiment 1. The difference was that a number of fruits, rather than only one piece of fruit, were presented for each trial. Examples of the two different arrangements are shown in Figures 2B and 2C. In one arrangement, the fruit to be grasped was presented with fruits of the same type (compatible distractors). In the other arrangement, it was presented with fruits of differing types (incompatible distractors). The laterally placed fruits were at an angle of 10–20° from the central fruit (note that no effects of position were found in Experiment 1). Under a no-distractor con-

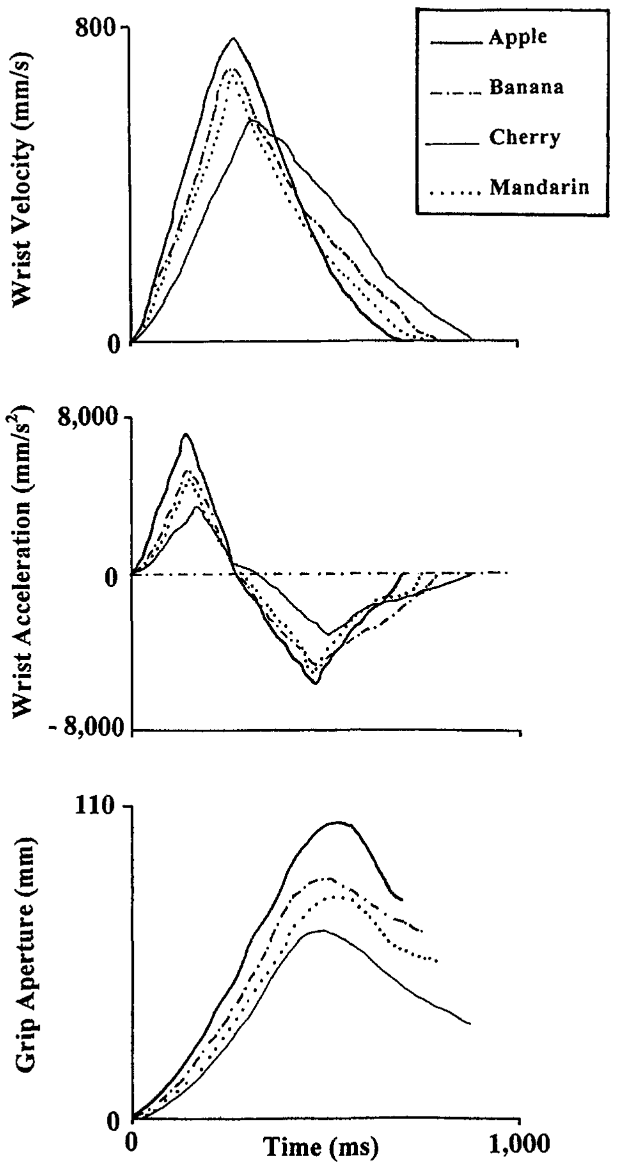

Figure 3. Velocity, acceleration, and grip aperture profiles of a single movement for each of the fruit types.

dition, the piece of fruit to be grasped was presented without distractors. In both cases, the distance between the starting position and each piece of fruit in the semicircular array was 30 cm. In all cases of differing fruit types, the height of each piece of fruit was adjusted (using an adjustable platform) so that the tops of all fruits were along the same plane. This leveling was to prevent jumps in the trajectories.

Procedure

In most respects, the procedure was the same as that described in Experiment 1. A warning tone was given, and when the target fruit became highlighted, the participant was required to reach for and grasp the fruit and bring it back to the starting position. The target fruit that was highlighted was central, ipsilateral, or contralateral. For each target fruit, a minimum of 7 trials was required. Thus, in the no-distractor condition, the participant reached seven times for an apple placed ipsilaterally, seven times for an apple placed contralaterally, and seven times for an apple placed centrally. The same conditions applied for the other three fruit types; the total number of no-distractor trials was 84. Under the compatible distractor condition, the participant again reached seven times to each type of fruit in each of the three positions shown in Figure 2B. This gave a total of 84 compatible distractor trials. Under the incompatible distractor condition, four pieces of fruit (one apple, one mandarin, one banana, and one cherry) were displayed (see Figure 2C). One was the target fruit, which was in any of the four positions. The other three pieces acted as distractors. Overall, there was a total of 96 possible target–distractor fruit combinations. With the provision that each type of fruit was the target for at least 3 combinations, 20 combinations were pseudorandomly chosen. The participant was required to perform 7 trials for each of these chosen combinations, giving a total of 140 incompatible distractor trials. The order of trial presentation according to distractor condition (no distractor, compatible, or incompatible) was counterbalanced across participants. The order of the various combinations for each condition was randomized. From trial to trial, the presentation was changed. Experimentation continued until the required number of trials had been performed.

Results and Discussion

The means for initiation time, movement duration, and the kinematic parameters of each component were computed. The variables analyzed were distractor condition (compatible, incompatible, or no distractor), type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension), and position of the grasped fruit in relation to the participants position (central, ipsilateral, or contralateral). The statistical methods that were used were the same as those described in Experiment 1. Results for the same type of fruit presented in isolation were compared with those obtained in Experiment 1.

Values are reported in Table 2. The incidence of errors was low (<1%); thus, they were not analyzed. The most noticeable finding was that for initiation time, movement duration, and all the kinematic variables analyzed, no significant results were found except for a greater variability of maximum grip aperture for some participants under the incompatible distractor condition (see the standard deviations in Table 2). To measure whether this variability varied across conditions, the transform method of O'Brien (1981) was used to test the trial-to-trial variability. No significant effects were found. An additional ANOVA comparing initiation time, movement duration, and kinematic values obtained in Experiments 1 and 2A for the same fruit presented in isolation showed no significant effects. However, the 6 participants in Experiment 2A were slower than those in Experiment 1. These prolonged movement durations in Experiment 2A were confined to the participant population of this experiment. In all of the other experiments (2B, 2C, 2D, 3, 4, 5, and 6) of the current study, such longer movement durations were not found. This finding suggests that a longer movement duration does not reflect an alteration in strategy in response to the presence of a distractor.

Overall, these results demonstrated that initiation time,

Table 2
Data (Collapsed for Fruit Type) for the Three Different Distractor Conditions in Experiment 2A

Variable	No distractor		Compatible distractor		Incompatible distractor	
	M	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	383	37	378	35	365	37
Movement duration (ms)	856	88	847	83	861	85
Transport component						
Time to peak velocity (ms)	354	28	342	31	360	35
%	41	5	40	5	41	4
Time to peak acceleration (ms)	230	21	222	25	235	24
%	26	2	26	3	27	2
Time to peak deceleration (ms)	532	56	523	53	536	54
%	62	7	61	7	62	5
Deceleration time (ms)	502	53	505	55	501	53
%	58	6	59	7	58	6
Amplitude peak velocity (mm/s)	561	64	584	65	548	62
Amplitude peak acceleration (mm/s^2)	6,473	633	6,588	641	6,325	632
Amplitude peak deceleration (mm/s^2)	6,280	624	6,340	655	6,125	649
Manipulation component						
Specification time (ms)[a]	233	26	248	25	239	25
%[a]	25	2	26	3	27	3
Time to maximum grip aperture (ms)	510	53	495	51	514	55
%	59	6	58	6	59	5
Amplitude grip aperture (mm)	76	7	74	8	77	16

[a] Only for cherries.

movement duration, and the movement kinematics of a reach-to-grasp movement were not obviously influenced by distractor fruits in the immediate vicinity of the fruit to be grasped. This finding suggests that parameterization for action is essentially predetermined and not subject to passive interference effects during the premovement and movement phases. Such a result is in agreement with previous studies (Chieffi, Gentilucci, Allport, Sasso, & Rizzolatti, 1993; Tipper et al., 1992) that have demonstrated that when distractors are not on the route between the hand starting position and the target, no interference effects are found.

Experiment 2B

To further verify the results from Experiment 2A, the distractor was presented along the hand trajectory (Tipper et al., 1992) in this experiment.

Method

Participants

Eight students (4 women and 4 men, aged 22–30 years) volunteered to participate; none had participated in Experiment 1 or 2A. They showed the same general characteristics as the participants in Experiments 1 and 2A. Each participant attended one experimental session of 1.5-hr duration.

Apparatus and Materials

The apparatus and the materials were the same as those described in Experiment 1. In a no-distractor condition, the fruit to be grasped was presented alone. In a compatible distractor condition, the fruit to be grasped was presented with fruits of the same type, whereas in the incompatible distractor condition, it was presented with fruits of differing types. Three pieces of fruit were placed between the starting switch and the target at 7.5 cm, 15.0 cm, and 22.5 cm from the target fruit (see Figure 4).

Procedure

In most respects, the procedure was the same as that described in Experiment 1. A warning tone was given, and when the target fruit became highlighted, the participant was required to reach for and grasp the fruit and bring it back to the starting position. The target fruit was always placed centrally and at the 30-cm position. For each compatible arrangement (n = 4), 7 trials were performed for each target fruit (N = 28). For each incompatible arrangement (n = 24), 7 trials were performed for each target fruit (N = 168). There were 7 experimental trials for each target fruit in the no-distractor condition. The order according to distractor condition (compatible, incompatible, or no distractor) was counterbalanced across participants. The order of the various combinations for each condition was randomized. From trial to trial, the presentation was changed.

Results and Discussion

Only the mean for the initiation time parameter was computed. The variables analyzed were distractor condition (compatible, incompatible, or no distractor), type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension). The statistical methods that were used were the same as those described in Experiments 1 and 2A. Kinematic analysis was not performed because the aim of this experiment was to further test whether

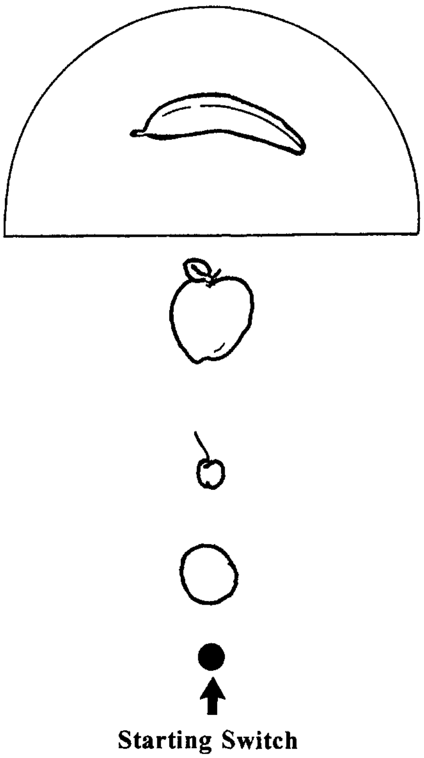

Figure 4. Example of the position of the fruit in Experiment 2B for the incompatible distractor condition.

interference effects are related to object distractor position as suggested by Tipper et al. (1992). In addition, because the distractor objects were positioned along the hand path, the necessary trajectory jumps would obviously lead to kinematic differences.

Values are reported in Table 3. The incidence of errors was low (<1%); thus, they were not analyzed. Most noticeably, no significant results were found for initiation time in relation to distractor condition. That is, even when a distractor was on the trajectory path, movement initiation time was not affected. A possible explanation for the difference between this study and that of Tipper et al. (1992) is that the latter researchers measured reaction time as opposed to movement initiation time. In the current study, I aimed to assess movement initiation and performance under typical behavioral conditions and thus placed no emphasis on the speed of response. In contrast, the participants in Tipper et al.'s study were required to respond as quickly as possible. Experiment 2C was thus conducted to determine whether placing more emphasis on promptly initiating the movement would reveal interference effects.

Table 3
Initiation Times (in Milliseconds) for Different Types of Fruit for the Distractor Conditions in Experiment 2B

	No distractor		Compatible distractor		Incompatible distractor	
Fruit	*M*	*SD*	*M*	*SD*	*M*	*SD*
Apple	337	29	341	37	335	38
Banana	342	35	337	34	338	36
Mandarin	338	30	345	35	340	36
Cherry	352	36	348	29	345	30

Experiment 2C

Even though the main goal of the previous experiments was to investigate typical behavioral requirements, it was of some interest to ascertain whether different instructions for movement initiation would reveal interference effects. Thus, in the present experiment, reaction time, rather than the unstressed initiation time, was assessed. I asked whether effects would be revealed because the reach was initiated as quickly as possible (Tipper et al., 1992). In such a speeded-response paradigm, would the need to inhibit the influence of a distractor object become evident?

One aim of this experiment was to compare the results from a distractor experiment, designed to parallel those in the literature that have incorporated a speed-instructed situation, with the results from a more ecologically valid situation. In this way, I hoped that some ideas could be advanced to explain the conditions that are necessary to reveal the requirement for distractor inhibition.

An additional point is that in Experiment 2B, the target fruit was always visible and placed at the 30-cm position. Because the participant already knew which object was the target and where it was located prior to reach onset, it is hardly surprising that no distractor interference effects on initiation time were observed. For example, following the practice trials, participants may have set up movement parameters for the target and, in subsequent trials, had no need to consider distractors that were never the goal of action. A further aim of Experiment 2C was to assess the role of advanced visual information of the target on interference effects from distractors.

Method

Participants

Eight students (4 women and 4 men, aged 23–29 years) volunteered to participate; none had participated in the previous experiments. They showed the same general characteristics as the participants in the previous experiments. Each participant attended two experimental sessions of 1.5-hr duration. The order of the experimental sessions was counterbalanced across participants.

Apparatus and Materials

The apparatus and the materials were the same as those described for Experiments 2A and 2B.

Procedure

In most respects, the procedures were the same as those described for Experiments 2A and 2B. Participants performed the tasks of Experiment 2A (Session A) and Experiment 2B (Session B) with the following differences:

Session A. The participants were instructed to begin the reach as soon as possible after fruit illumination. In addition, only one distractor was presented, either to the right or to the left of the target fruit (always central). This single distractor was compatible or incompatible with the target fruit. The use of a single distractor was to avoid possible confounds due to distractor identity, number of distractors, or both.

Session B. The participants did not know in advance the type of fruit target or the type of fruit distractor. Before each trial, the participants' view was occluded by a mask while the fruit was positioned. Immediately prior to target fruit illumination, the mask was removed. In all other respects, this session was the same as Session A in terms of the instructions and the number and the type of distractors. In this case, however, the distractor fruit was placed along the trajectory path, midway between the starting position and the target fruit.

Note that in both sessions, no emphasis was placed on the speed of the movement after departure. This is because prehension movements performed at maximum speed, in absence of distractors, show kinematics that are dramatically different from those performed at a normal rate (Wing, Turton, & Fraser, 1986).

Results and Discussion

The means for reaction time, movement duration, and the kinematic parameters of each component were computed. The variables analyzed for Session A were distractor condition (distractor or no distractor), distractor type (compatible or incompatible), distractor position (right or left), and type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension). The variables analyzed for Session B were distractor condition (distractor or no distractor), distractor type (compatible or incompatible), and type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension). The statistical methods that were used were the same as those described in Experiment 1. Results for the same type of fruit presented in isolation were compared with those obtained in Experiment 1.

The incidence of errors was low (<1% for both sessions); thus, they were not analyzed. In general, no effects on reaction times or movement kinematics were found for either session. That is, interference effects were not revealed by asking the participants to begin the movement as quickly as possible. In addition, the fact that the target and distractor fruits were seen only briefly prior to trial onset generally did not change the results found in the previous experiments. Relative values of the temporal kinematic parameters of Sessions A and B corresponded. It could be argued that this lack of interference is not surprising because participants were always aware that the target would be central (rather than in any one of the four positions in Experiment 2A). In this way, they could prepare the response prior to the cue. If this were the case, the expectation would be for different results in Experiments 2A and 2C. However, no differences in reaction times or in the relative values of kinematic parameters were found.

The only significant finding in Session B, where the distractor was on the trajectory path, was for reaction time in relation to distractor condition. That is, when a distractor was on the trajectory path, reaction time was slower than when the distractor was not presented (*M*s = 282 ms vs. 268 ms, respectively), $F(1, 7) = 2.65$, $p < .05$. However, a closer inspection of this result demonstrated that the source of this interference effect was related to the condition whereby an apple was positioned on the trajectory path ($p < .05$). Of all the fruits, the apple occupied the greatest space in all dimensions. As such, the participant might have needed to place a certain level of attention on this fruit for planning the physical avoidance of this distractor. In this respect and as more fully discussed in Experiment 5, there is an active attending to the distractor fruit. A possible explanation, once again, for the difference between the results for reaction time obtained in the present study and those of previous experiments (Tipper et al., 1992) may lie in the fact that in an ecological situation where selection is performed for a natural action, distractors may be filtered prior to the movement response with selective parameterization not entailing substantial passive processing of distractors. In contrast, the very fast, simple reaction times of a strictly learned experimental situation may require a high preparatory state that is difficult to maintain when extraneous stimuli are presented. Thus, a to-be-ignored stimulus could contribute to a marked slowing of simple reaction time (Davis, 1959).

It could be proposed that a condition requiring the participant not only to start as soon as possible but also to reach and grasp as quickly as possible without consideration of accuracy would reveal more substantial interference. However, and as mentioned previously, fast movements show dramatic changes in the kinematics of the reach-to-grasp movement for a single target (Wing et al., 1986). Thus, it would be difficult to divide distractor effects from the intrinsic kinematic disruption.

Experiment 2D

Differences between the results of the current study and those of previous experiments (Tipper et al., 1992) may relate to the type of upper limb movement performed. In a pointing–touching action, the transport component is activated in isolation, having been parameterized to correspond to the action goal. When one is reaching to grasp an object, the transport component is activated in parallel with manipulation and thus is part of a goal-directed action where grasping the object represents the purpose of the movement. Interference effects may differ according to the relationship of each movement component to the action goal. To investigate this effect, Experiment 2D assessed pointing movements under speeded and nonspeeded conditions.

Method

Participants

Eight students (4 women and 4 men, aged 21–30 years) volunteered to participate; none had participated in the previous experiments. They showed the same general characteristics as the participants in the previous experiments. Each participant attended one experimental session of 1-hr duration.

Apparatus and Materials

The apparatus and the materials were the same as those described for Experiments 2A and 2B. In this case, however, markers were placed only on the wrist and on the tip of the index finger. Analysis of the wrist marker kinematics allowed a comparison of the results for the transport (reaching) component with those from the previous experiments. Analysis of the index-finger marker kinematics allowed a comparison with previous studies (Tipper et al., 1992).

Procedure

The procedures related to target fruit and distractor fruit positioning and conditions were exactly the same as those described in Session A of Experiment 2C. Rather than reaching to grasp the fruit, however, participants were required to point to and touch the fruit. For half of the trials, participants were instructed to respond as quickly as possible to fruit illumination. For the other half of the trials, participants received no speed instruction. The order according to instruction was counterbalanced across participants.

Results and Discussion

The means for reaction time, movement duration, and the kinematic parameters of the two markers were computed. The variables analyzed were distractor condition (distractor or no distractor), distractor position (right or left), type of fruit (cherry, banana, mandarin, or apple), and response speed condition (speeded or unspeeded).

For reaction time and all of the kinematic parameters, no significant effects of distractor were found. This result was irrespective of instruction (speeded vs. unspeeded). In accordance with previous studies (Gentilucci et al., 1991; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeir, 1987), the arm trajectories changed their shape when targets of different size were used. Analysis of the wrist marker showed that movement duration was longer for the banana and the cherry than for the apple and the mandarin. The peaks of velocity, $F(3, 21) = 58.04$, $p < .0001$; acceleration, $F(3, 21) = 45.14$, $p < .0001$; and deceleration, $F(3, 21) = 62.23$, $p < .0001$, were all lower for the cherry and the banana than for the apple and the mandarin. Modifications in the length of the deceleration phase of the trajectory were also found. Thus, the deceleration phases for the cherry and the banana were longer than those for the apple and the mandarin, $F(3, 21) = 71.24$, $p < .0001$. Analysis of the index-finger marker revealed results that mirrored those of the wrist marker.

Even though the reaction time parameter (initiation time for the unspeeded condition) showed no appreciable change across conditions, it was of interest to find that it showed greater variability ($ps < .05$; O'Brien, 1981) for the speeded responses. In other words, it was more the requirement to react as quickly as possible rather than the presence of distractors that revealed effects.

Null effects must always be taken with caution. However, despite a spatial error of 0.04 mm for the calibrated working space and a calculation of reaction times to the nearest millisecond, there was a definite failure in being able to reveal effects from the presence of a distractor on a host of analyzed dependent variables. This finding is in line with previous studies of very demanding and continuous tasks that have involved selection and production, where virtually no interference has been found (Allport, Antonis, & Reynolds, 1972; L. H. Shaffer, 1975).

Results from the experiments that assessed a speeded response generally found no interference effects except for changes to the variability of some parameters. Therefore, only unspeeded conditions were considered in the following experiments. This is also in line with the main intention of extending the investigation of the role played by distractor objects for planning actions to more ecological situations where speed is usually not emphasized yet relevant–irrelevant information needs to be processed (e.g., reaching for a fruit or a glass of water).

Experiment 3

In Experiments 2A–D, both the fruit to be grasped and the distractor fruits were presented before the onset of movement. Thus, the absence of distractor effects could be related to premovement exclusion of the irrelevant fruit motor program. An alternative explanation is that there is a dissociation between global and focal attentional mechanisms for the parameterization of movement. A global selective mechanism may allow for continued access to the different motor outputs required to grasp any of the presented fruits. Focal selective mechanisms may then act to specify motor parameterization for one piece of fruit. It can be hypothesized that the spatiotemporal kinematics of motor output are initially planned at a global level but that with the subsequent process of attentional filtering, parameterization for the relevant fruit is chosen, and the appropriate movement is selected and executed. A way to verify this dissociation would be to present the distractors at different times during the movement for the target fruit. If there is a global–focal gradient for motor implementation, differential interference effects should appear. The aim of Experiment 3 was to determine whether the presence of a distractor fruit exerted interference effects and, if so, at what point in the premovement and movement phase such effects were strongest.

Method

Participants

Eight students (4 women and 4 men, aged 22–28 years) volunteered to participate; none had participated in Experiment 1 or 2. Each participant attended one experimental session of 2-hr duration.

Apparatus and Materials

The apparatus and the materials were the same as those described for Experiments 2A–D except that a distractor fruit could be illuminated at different points of the ongoing movement (Figure 1): (a) immediately following release of the starting switch (A1), (b) crossing a photoelectric cell (DIELL-BSC005 C) at one third of the distance between the starting position and the target fruit (A2; 10 cm), or (c) crossing another photoelectric cell after an additional 10 cm (A3). Spotlight highlighting of the distractor fruit was triggered by either release of the starting switch or the crossing of the relevant photoelectric cell. The target fruit was presented centrally, ipsilaterally, or contralaterally with respect to the participant. Through a dark–light interplay (a part of the table was kept in the dark), the distractor fruit was hidden before movement departure and highlighted when necessary. It, too, was central, ipsilateral, or contralateral.

Procedure

As in the previously described experiments, the participant was given a warning tone and, when the target fruit was highlighted, was required to reach for and grasp this fruit and bring it back to the starting position. No emphasis was placed on reaching as quickly as possible. Ten trials for each of the three distractor appearance conditions (A1, A2, or A3) were presented in a counterbalanced order among a total of 60 trials. For the remaining 30 trials, no distractor was presented.

Given that Experiments 1 and 2 demonstrated no effects due to position, the placement of both the target and the distractor fruits was randomized. Selection according to type of target and distractor fruits was also randomized.

Results and Discussion

Initiation time, movement duration, and kinematics were recorded and analyzed as they were in the previous experiments. The variables analyzed were distractor appearance (A1, A2, A3, or no distractor), type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension), and target fruit position (central, ipsilateral, or contralateral).

Values are reported in Table 4. Errors were less than 1% and were not analyzed. Of primary interest is that no effects were found in relation to distractor appearance condition. Initiation time showed no differences. The duration of the movement did not change according to whether the distractor was presented at movement onset or later. Similarly, the parameters of the transport and manipulation components showed no differences. The only significant finding was an increase in the variability of grip aperture for the A2 distractor appearance condition. However, no significant differences of trial-to-trial variability across conditions were found with O'Brien's (1981) test.

Furthermore, an ANOVA comparing initiation time, movement duration, and kinematic values obtained in Experiments 1 and 2 with those obtained in Experiment 3 showed no significant effects.

For this experiment, results again appeared to be against the idea of distractor effects. Regardless of whether the

Table 4

Data (Collapsed for Fruit Type) for the Four Different Distractor Appearance Conditions in Experiment 3

	No distractor		A1		A2		A3	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	348	35	341	37	354	31	339	34
Movement duration (ms)	723	81	737	79	727	79	740	82
Transport component								
Time to peak velocity (ms)	301	26	314	30	299	28	311	28
%	41	3	42	4	41	3	42	3
Time to peak acceleration (ms)	189	20	205	19	191	19	202	22
%	26	2	27	3	26	3	27	3
Time to peak deceleration (ms)	443	45	452	48	439	44	448	46
%	61	5	61	5	60	7	60	5
Deceleration time (ms)	422	44	423	45	428	42	429	44
%	58	6	57	6	58	5	57	5
Amplitude peak velocity (mm/s)	822	80	777	81	801	80	769	78
Amplitude peak acceleration (mm/s^2)	7,824	793	7,643	751	7,781	783	7,684	773
Amplitude peak deceleration (mm/s^2)	7,112	710	6,987	692	7,001	700	6,899	682
Manipulation component								
Specification time (ms)[a]	209	21	212	20	209	22	218	20
%[a]	28	3	28	3	28	3	29	3
Time to maximum grip aperture (ms)	458	51	471	50	465	52	480	50
%	63	5	63	6	63	5	64	6
Amplitude grip aperture (mm)	80	9	84	8	78	16	83	8

Note. A1 = distractor fruit was illuminated immediately following release of the starting switch; A2 = distractor fruit was illuminated after crossing a photoelectric cell at one third of the distance between the starting position and the target fruit (10 cm); A3 = distractor fruit was illuminated after crossing another photoelectric cell after an additional 10 cm.

[a] Only for cherries.

distractor was presented before or during the movement, the chosen action was appropriately executed and concluded.

Experiment 4

The results from the previous experiments suggest that the presence of fruit distractors generally did not obviously interfere with the kinematic parameterization for the reach to grasp of a target fruit. Rather than viewing a neighboring piece of fruit solely as a distractor to the target fruit movement, it could also be considered as a facilitator for movement to the distractor fruit. For example, if parameterization for a distractor is computed in parallel to that for the target object (Tipper et al., 1992), facilitatory effects from the distractor may play an important role under perturbation conditions (Castiello, Bennett, & Mucignat, 1993; Castiello et al., 1992; Castiello, Bennett, & Stelmach, 1993; Castiello & Jeannerod, 1991; Castiello, Paulignan, & Jeannerod, 1991; Gentilucci, Chieffi, Scarpa, & Castiello, 1992; Haggard, 1994; Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991). A simple experimental example can be used to illustrate this concept. A target fruit, such as an apple, is presented in a central midsagittal position. Immediately after movement onset to this target, a neighboring fruit is unexpectedly highlighted, and the participant must grasp this latter fruit. In other words, the participant prepares for the grasp of one fruit but with visual perturbation must suddenly shift to parameterization for another. The assessment of facilitatory effects is performed by manipulating the participant's awareness of what fruit will be the perturbation target. For example, if prior to the movement, the participant is aware of the type and the position of the fruit to grasp in cases of perturbation, the perturbation response may be facilitated. In contrast, if the participant becomes aware of the type and the location of the perturbed fruit after movement onset, facilitatory effects on the perturbed response will presumably be less.

Method

Participants

Eight students (4 women and 4 men, aged 21–30 years) volunteered to participate; none had participated in the previous experiments. Each student participated in six experimental sessions, each of 1-hr duration.

Apparatus and Materials

The apparatus and the materials were the same as those described for the previous experiments. A piece of fruit (apple, mandarin, banana, or cherry) was placed 30 cm directly in front of the participant. This piece of fruit was visible before being illuminated. Another piece of fruit was placed 20° to the left or to the right of this central fruit (Figure 1). Before the trial began, this piece of fruit was either visible or not visible. In order to have the most interfering conditions, the central and the lateral fruits were always of a different type; that is, if the central piece was an apple, the lateral piece was a mandarin, a banana, or a cherry. This gave a total of 12 fruit presentation conditions.

Perturbation was triggered by release of the starting switch, that is, by the onset of the reaching movement. This perturbation consisted of a switch of spotlight illumination from the central to the lateral fruit. When this lateral fruit was visible (but not highlighted) before the trial onset, this meant that the participant knew the type and the location of the fruit to grasp in the case of perturbation. In contrast, when this fruit was not visible before trial onset, these characteristics became apparent only when the fruit was spotlighted in a perturbed trial after movement onset. Theoretically, the former condition (before) should have greater facilitatory effects on the parameterization of the perturbed movement than the latter condition (after).

Procedure

The participant was instructed to begin the movement as soon as the central fruit was spotlighted, but no emphasis was placed on the speed of this response. If there was no change of spotlight (nonperturbed trials), the requirement was to grasp this central fruit. For 200 trials of an experimental session, 160 were nonperturbed trials, and for 80 of these a lateral fruit was visible before trial onset (right, $n = 40$; left, $n = 40$). For the 40 perturbed trials, the spotlight shifted to the lateral fruit, and the participant was required to grasp this latter fruit. Twenty of these perturbed trials were to a fruit on the left (perturbed left trials) and 20 to a fruit on the right (perturbed right trials) of the central fruit. For 20 of the perturbed trials, the lateral fruit was visible before trial onset (before); for the other 20, it became visible only with the perturbation.

Six experimental sessions were conducted, each on a different day. The 12 fruit presentation pairs were counterbalanced within and across these experiments, meaning that both the central and the lateral fruits were changed regularly. However, the participant was not able to see the process of changing the fruit, and this process did not necessarily coincide with the delivery of a perturbed trial. Presentation of perturbed trials and before–after trials was randomized.

Results and Discussion

Initiation time, movement duration, and kinematic values were analyzed in the same way as those described in Experiment 1. The variables analyzed were distractor appearance (before or after), type of trial (nonperturbed, perturbed right, or perturbed left), and type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension). Statistical analysis was the same as that described previously.

Values are presented in Table 5. Errors were less than 2% and were not analyzed. In previous perturbation studies, the adaptive mechanisms differed according to whether the perturbation was to the transport (perturbation of object position) or the manipulation (perturbation of type of grasp) component. In the former case, the more striking effects are a significant temporal anticipation of the first peak of acceleration and a prolongation of movement duration for perturbed trials as compared with nonperturbed trials (Castiello et al., 1991; Paulignan, MacKenzie, et al., 1991). In the latter case, under conditions where the perturbation

Table 5
Data for the Two Stimuli Display Presentation Conditions in Experiment 4

	Before						After					
	Nonperturbed		Perturbed left		Perturbed right		Nonperturbed		Perturbed left		Perturbed right	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	372	38	368	40	366	37	382	39	374	41	379	40
Movement duration (ms)	770	69	812	84	820	82	779	80	815	82	810	83
Transport component												
Time to peak velocity (ms)	326	31	294	28	303	29	331	30	300	33	295	31
%	42	4	36	3	37	4	42	4	36	3	36	5
Time to peak acceleration (ms)	200	21	177	18	184	20	205	19	181	19	190	20
%	25	2	21	3	22	3	26	3	22	2	23	2
Time to peak deceleration (ms)	479	46	453	47	458	46	482	49	442	43	453	46
%	62	6	55	4	55	7	61	7	54	5	55	5
Manipulation component												
Time to maximum grip aperture (ms)	485	50	441	44	452	46	490	50	450	47	452	46
%	62	5	54	5	55	5	62	6	55	6	56	5

Note. Before = the participant knew the type and the location of the fruit to grasp in case of perturbation; After = the participant did not know the type and the location of the fruit to grasp in case of perturbation.

requires the suppression of one grasp program and the activation of another, the correction is later and consists more obviously of a temporal anticipation of peak deceleration but no change to movement duration (Castiello, Bennett, & Stelmach, 1993). In the current experiment, both the transport and the manipulation components were perturbed. Perturbation is of the transport component because a change in arm trajectory from the central to the lateral fruit is required. Perturbation is of the manipulation component because a change in grasp type is required when one is shifting from one to another fruit type.

The main purpose of this experiment was to compare the results from the before distractor appearance condition with those from the after condition. Thus, the results were collapsed across the 12 presentation combinations for the perturbed and nonperturbed trials. In summary, the comparison between the before and after presentation conditions gave no significant findings. In other words, there appeared to be no facilitatory effects from the premovement awareness of what the perturbation fruit would be and where it would be located. However, the comparison between perturbed and nonperturbed trials showed results that resembled those from previous perturbation experiments. Movement duration was longer for the perturbed trials than for the nonperturbed trials, $F(2, 14) = 12.04, p < .001$. Kinematic events measured from both components were earlier for perturbed trials than for nonperturbed trials. This anticipation has been taken to indicate that the first output is curtailed to allow for mobilization of the second output (Castiello et al., 1992; Castiello, Bennett, & Stelmach, 1993; Paulignan, Jeannerod, et al., 1991; Paulignan, MacKenzie, et al., 1991). Looking at the transport component, the peaks of velocity, acceleration, and deceleration were all earlier for perturbed trials than for nonperturbed trials: absolute $F(2, 14) = 9.12$, $p < .01$, and relative $F(2, 14) = 6.98, p < .05$, for time to peak velocity; absolute $F(2, 14) = 8.23$, $p < .05$, and relative $F(2, 14) = 7.02, p < .05$, for time to peak acceleration; and absolute $F(2, 14) = 8.10, p < .05$, and relative $F(2, 14) = 6.43, p < .05$, for time to peak deceleration. In other words, the initial reach movement to the central fruit was interrupted so that execution of the reach movement to the lateral fruit could occur. For the manipulation component, the peak grip aperture was earlier for perturbed trials than for nonperturbed trials: absolute $F(2, 14) = 11.21, p < .001$, and relative $F(2, 14) = 6.66$, $p < .05$. Again, this finding indicates that the pregrip mechanisms (Arbib, 1981) for the central fruit were halted so that those for the lateral fruit could be initiated.

The amount of anticipation for each of the transport and manipulation parameters showed no difference when the before condition and the after condition were compared. Peak acceleration, for example, was 30–40 ms earlier for perturbed trials than for nonperturbed trials, and this effect was irrespective of whether or not there was awareness of the perturbation fruit prior to movement onset. Similarly, peak grip aperture was also 30–40 ms earlier with perturbation, but again, there was no difference between the before and after conditions. This finding suggests that the timing of corrective mechanisms was not influenced by selective attentional mechanisms. Even when variability was assessed, it became clear that preperturbation knowledge of the perturbation fruit did not smooth the output, leading to less variability. For all parameters, there was no difference of variability when the before and after conditions were compared.

Overall, these results confirmed that central mechanisms can rapidly respond to a perturbation of both object type and location by anticipating key kinematic parameters. In this way, the first output is halted so that parameterization for the second output can be suitably executed. Facilitation of these anticipation mechanisms does not appear to occur if participants are given preperturbation awareness of the type and the location of the perturbation object.

Experiment 5

Results from the previous four experiments favor the idea of a strong selection-for-movement parameterization before movement initiation. The distractor techniques used generally did not lead to any modifications to initiation time, movement duration, or the kinematic parameters of motor output. No interference was produced by presenting distractor fruits requiring similar or different grasping actions. In light of these results, it can be proposed that, prior to movement initiation, selective attentional mechanisms play a role in directing necessary and relevant information for the implementation of the correct motor program (Keele, 1981) and that this selection appears to almost totally exclude parallel computations.

As mentioned previously, current knowledge of visuospatial attention is, for the most part, based on studies that have been conducted within a two-dimensional world (Posner, 1978; for a review, see Umiltá, 1988). Relatively little research has examined how spatial attention is distributed in three-dimensional space (Andersen & Kramer, 1993; Downing & Pinker, 1985; Gawryszewski, Riggio, Rizzolatti, & Umiltá, 1987; Umiltá, Castiello, Fontana, & Vestri, 1995) and, in particular, how spatial selective attentional mechanisms, such as covert orienting and focusing, are used when one is reaching to grasp an object. In Experiment 5, distractors and a dual-task procedure were used in an attempt to dissociate the focus of attention from the target position in a prehension task. I hypothesized that once parameterization is completed, a specific focusing of the attentional system assists in driving the hand toward the object. I predicted that an active deviation of this focus from the target area, and thus a loss of anchor, would result in changes to the motor output.

Method

Participants

Eight students (4 women and 4 men, aged 18–25 years) volunteered to participate; none had participated in the previous experiments.

Apparatus and Materials

The apparatus and the materials were the same as those for the previously described experiments. Horizontal eye movements were recorded with two Ag/AgCl electrodes (diameter of 6 mm) positioned on the inner and outer canthi of the right orbit. The recorded signals were amplified (10^4), filtered using a Butterworth filter, and digitized using a sampling frequency of 100 Hz. An algorithm determined the number of sample points whereby the electrooculogram signal exceeded a threshold of ± 80 μV. If this number exceeded 20, eye movement was assumed to have occurred, and the trial was rejected.

Procedure

This experiment consisted of three sessions. Session A always preceded Session B, but in all other respects, the order of sessions was counterbalanced across participants. Experimentation continued over a 10-day period.

Session A: Reach and grasp only. The participant was required to reach for and grasp a fruit placed 30 cm in front of the starting switch while maintaining gaze fixation on this fruit. Of 40 trials, there were 10 to each type of fruit (cherry, banana, mandarin, and apple). The order of these blocks of 10 trials was counterbalanced. The mean movement duration for each type of fruit was calculated immediately after each block.

Session B: Count only. A piece of fruit (cherry, banana, mandarin, or apple) was placed 30 cm in front of the starting switch. Another piece of fruit was placed 20° either to the left or to the right of this central fruit. A spotlight positioned directly above the lateral fruit intermittently highlighted this fruit at a frequency of 10 Hz. Such a fast rate was chosen in order to avoid jumps of attention between the lateral and the target fruit. Highlighting began at trial onset (as signaled acoustically) and continued for the mean movement duration (Session 1) plus 10 s. The end of the trial was then also acoustically signaled. The participant was required to maintain gaze fixation on the central fruit but to mentally count the number of times that the lateral fruit was highlighted between the trial onset and end times. The participant then had to report this count after each trial. Note that no reach-to-grasp movement was performed.

The lateral fruit could be of the same (compatible distractor) or a different (incompatible distractor) type as the central fruit. Ten trials for each type of lateral fruit and for each side (right or left) were conducted for each type of central fruit. This gave a total of 320 trials (e.g., central fruit: apple, $n = 10$; lateral fruit: cherry, $n = 10$; banana, $n = 10$; mandarin, $n = 10$). The trials were conducted in batches of 80 with intervening rest periods. The order according to type of central fruit, type of lateral fruit, side of lateral fruit, and compatibility was counterbalanced across participants.

Session C: Simultaneous. The first and second sessions gave information on typical movement durations and distractor counts, which provided comparisons for Session C, in which the two tasks were performed simultaneously. In Session C, the participant was required to reach for and grasp the central fruit while maintaining gaze fixation on this same fruit. At the same time, the participant was required to count the number of times that a laterally placed distractor fruit was highlighted and then report this count at the end of the trial. A warning tone was given, and the participant was required to start movement when the central fruit was highlighted. Intermittent spotlighting of the lateral fruit began before movement onset (A1), at movement onset (i.e., with release of the starting switch; A2), when the reaching arm passed a photoelectric cell 10 cm in front of the starting switch (A3), or when the arm passed another photoelectric cell 20 cm in front of the starting switch (A4). This spotlighting continued for the period of the movement plus an additional 10 s. Another acoustic signal then indicated the end of the trial.

The total number of trials in Session C was 1,320. Over a period of 10 days, these trials were performed in batches of 132 with frequent rest periods. The presentation and the counterbalancing of the central and lateral fruits were the same as those described for Session B in terms of type, side, and compatibility. In addition, for each type of central fruit, no distractor fruit was presented for 10 trials (no-distractor condition). For each type of central and lateral fruit combination, there were 10 trials for each type of spotlighting onset (e.g., central fruit: apple; lateral fruit: apple; spotlight onset: A1, $n = 10$; A2, $n = 10$; A3, $n = 10$; A4, $n = 10$). Marker position was kept constant across experimental sessions by marking the points of application with indelible ink.

Results and Discussion

Initiation time, movement duration, and kinematic variables were recorded and analyzed as they were for the other experiments. The variables analyzed were onset of distractor spotlighting (A1, A2, A3, or A4), type of distractor (compatible, incompatible, or no distractor), type of central fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension), type of distractor fruit (cherry, banana, mandarin, or apple), and distractor fruit position (left or right). Two additional ANOVAs were performed. In one case, the variable was count (count only or simultaneous). In the other case, the variable was movement duration (reach and grasp or simultaneous). The data for all of the kinematic variables were compared between the independent reach-and-grasp condition and the simultaneous condition.

The mean values for each parameter are shown in Table 6. Eye movements occurred in less than 3% of the total number of trials. The data from these trials were discarded. There were no statistical differences between the count-only condition and the simultaneous condition (A2). This finding indicates that the performance of the reach-to-grasp movement had no obvious effect on the ability to covertly orient attention to a nonfoveated lateral stimulus. The average count numbers were 74 ($SD = 8$) and 71 ($SD = 8$) for the count only and simultaneous conditions, respectively.

However, the kinematic results indicate that the movement was affected by the act of covertly orienting attention to a stimulus that was not the one to be grasped (Table 6). This was particularly evident when the results were compared across the four spotlighting-onset conditions. In Condition A1, that is, when spotlighting of the distractor fruit began before movement onset, the movement was slower and longer than it was for the other three conditions. Movement duration was longer for this A1 condition than it was for the no-distractor A2, A3, and A4 conditions, $F(4, 28) = 8.03$, $p < .05$. The speed of movement (amplitude of peak velocity) and its accelerative–decelerative bursts (amplitude peak acceleration–amplitude peak deceleration) were all lower for A1 than for the other conditions: $F(4, 28) = 7.32$, $p < .05$, for amplitude of peak velocity; $F(4, 28) = 8.12$, $p < .05$, for amplitude of peak acceleration; and $F(4, 28) = 8.85$, $p < .05$, for amplitude of peak deceleration. The time at which key transport (peak acceleration, peak velocity, and peak deceleration) and manipulation (peak grip aperture) parameters occurred was later for the A1 condition: absolute $F(4, 28) = 6.13$, $p < .05$, and relative $F(4, 28) = 6.88$, $p < .05$, for time to peak acceleration; absolute $F(4, 28) = 7.02$, $p < .05$, and relative $F(4, 28) = 5.84$, $p < .05$, for time to peak velocity; and absolute $F(4, 28) = 7.47$, $p < .05$, and relative $F(4, 28) = 7.72$, $p < .05$, for time to peak deceleration. These results suggest that the act of covertly orienting attention to a distractor fruit had its greatest effect on movement parameterization when this orientation occurred prior to movement onset. That is, parameterization was affected by dissociating the focus of attention from the target area during the movement planning period.

Furthermore, parameterization was affected by covertly orienting attention at later stages of the movement. For example, the time of peak acceleration was later for the A3

Table 6

Data (Collapsed for Fruit Type) for the Five Distractor Conditions in Experiment 5

	No distractor		A1		A2		A3		A4	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	374	41	381	40	378	40	388	39	376	41
Movement duration (ms)	778	82	845	84	785	81	794	80	780	79
Transport component										
Time to peak velocity (ms)	312	32	368	38	309	35	330	32	333	31
%	40	3	44	5	40	4	42	4	42	3
Time to peak acceleration (ms)	193	20	253	24	200	20	218	21	220	22
%	25	3	29	3	25	4	27	3	28	3
Time to peak deceleration (ms)	480	44	552	52	490	48	468	48	487	50
%	61	6	65	7	62	6	58	5	62	7
Deceleration time (ms)	466	47	477	46	476	48	464	47	447	46
%	59	6	56	8	60	7	58	6	57	6
Amplitude peak velocity (mm/s)	803	85	722	78	818	90	810	83	800	86
Amplitude peak acceleration (mm/s^2)	7,622	734	6,588	661	7,512	777	7,495	763	7,520	748
Amplitude peak deceleration (mm/s^2)	7,024	694	6,181	622	7,223	713	7,117	689	7,006	743
Manipulation component										
Specification time (ms)[a]	212	21	256	24	214	23	218	22	222	23
%[a]	27	3	30	4	27	3	27	4	28	3
Time to maximum grip aperture (ms)	487	51	561	55	493	49	471	50	490	48
%	62	6	66	7	63	5	59	6	62	6
Amplitude grip aperture (mm)	86	13	85	12	83	14	87	12	85	12

Note. Intermittent spotlighting of the lateral fruit began before movement onset (A1), at movement onset (i.e., with release of the starting switch; A2), when the reaching arm passed a photoelectric cell 10 cm in front of the starting switch (A3), or when the arm passed another photoelectric cell 20 cm in front of the starting switch (A4).

[a] Only for cherries.

and A4 conditions than for the A2 condition (*ps* < .05). The times of both peak deceleration and peak grip aperture were later for the A2 and A4 conditions than for the A3 condition. The results for this comparison between A2, A3, and A4 conditions are thus less clear-cut than those for A1 but do at least indicate that movement parameterization is in some way interfered with by having to direct attention away from the target area during the movement. The finding that no participants showed correlations between the time to peak grip aperture (manipulation) and the time to peak deceleration (transport) for the A1, A2, and A3 conditions can also be used as an indication of the importance of maintaining attention on the target area during premovement and early movement periods for coordination between the reach and grasp components. For the A4 condition, correlations were sometimes present.

Other results also suggest interference effects on movement parameterization. In particular, the parameter of amplitude of peak grip aperture showed an interaction between the type of distractor fruit and the type of central fruit grasp, $F(2, 14) = 6.62$, $p < .05$ (see Figure 5). In summary, the amplitude of peak grip aperture was influenced by the lateral fruit. If, for example, the central target fruit was a cherry, the amplitude of peak grip aperture was greater when the distractor fruit was an apple than when it was a banana. Conversely, the amplitude of peak grip aperture for the grasp of an apple was less when the lateral fruit was a cherry than when it was a mandarin. The distractor thus appeared to disturb the correct output. Further support for this interference effect was provided by the finding of increased variability for the parameters of movement duration and amplitude of peak grip aperture under the incompatible condition as compared with the compatible condition (*ps* < .05). These results of greater trial-to-trial variability demonstrated that the task of orienting attention to a nontarget stimulus when participants were reaching to grasp a target stimulus led to greater individual variance in performance.

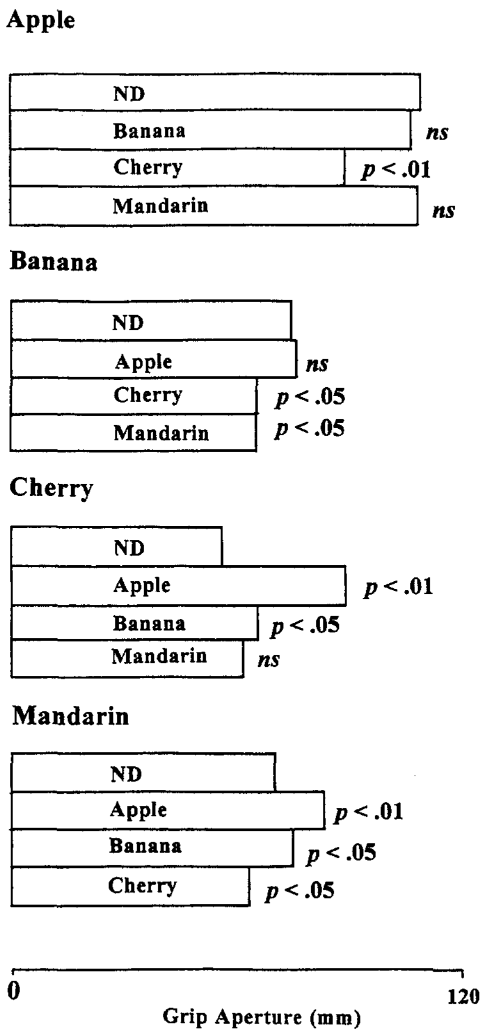

Figure 5. Results for the parameter of amplitude of grip aperture for the no-distractor (ND) condition and the different fruit distractor conditions.

Experiment 6

In Experiment 5, the participant was required to count the number of times that a distractor fruit was highlighted while reaching to grasp a target fruit. When this process of counting began prior to movement onset, there were obvious effects on the initiation time and its parameterization. It was concluded that the act of actively directing covert attention to the distractor fruit resulted in some disturbance to the upper limb reach to, and grasp of, the target fruit.

However, an alternative explanation is that the act of counting the number of times that a fruit is highlighted may in itself contribute to movement disruption. For this reason, in Experiment 6, the participant was required to count the number of times that the target, rather than a distractor fruit, was highlighted. That is, the object on which overt and covert attention was focused (counting) also had to be grasped. In this way, the effects from performing a secondary counting task could be dissociated from the effects of actively directing covert attention to a distractor (as in Experiment 5). I predicted that the movement would show little disturbance if the conclusion given in Experiment 5 holds true.

Method

Participants

Eight students (4 women and 4 men, aged 23–30 years) volunteered to participate; none had participated in the previous experiments.

Apparatus and Materials

The apparatus and the materials were the same as those for Sessions A and C of Experiment 5.

Procedure

The procedure was essentially the same as that for Session C of Experiment 5. The participant was required to reach for and grasp the central fruit while maintaining gaze fixation on this same fruit. At the same time, the participant was required to count the number of times that this fruit was highlighted and then report this count at the end of the trial. A warning tone was given, and the participant was required to start the movement when the central fruit was highlighted. Intermittent spotlighting began before movement onset (A1), at movement onset (i.e., with release of the starting switch; A2), when the reaching arm passed a photoelectric cell 10 cm in front of the starting switch (A3), or when the arm passed another photoelectric cell 20 cm in front of the starting switch (A4). This spotlighting continued for the period of the movement plus an additional 5 s. Another acoustic signal then indicated the end of the trial.

A total of 80 trials was performed by the participant in one session of 1.5-hr duration. An additional difference between this and the previous experiment was that the interval between the illuminations of the target fruit varied randomly from 100 to 400 ms (from 2.5 to 10.0 Hz). This variability was introduced to prevent the participant from estimating the constant interval and then multiplying, instead of counting, the number of illuminations.

Results and Discussion

Initiation time, movement duration, and kinematic variables were recorded and analyzed as they were for the other experiments. The variables analyzed were type of fruit grasp (precision grip, clench, small whole-hand prehension, or whole-hand prehension) and onset of spotlighting (no spotlighting, A1, A2, A3, or A4).

The mean values for each parameter are shown in Table 7. Of note is that for all dependent variables, irrespective of when spotlighting began, performance of the secondary task (counting) did not influence the kinematics of the prehension movements. In fact, no differences in the means were found when the no-spotlighting condition was compared with all of the spotlighting conditions. Furthermore, an ANOVA confirmed that the results in the no-spotlighting condition mirrored those obtained in Experiment 1. In Experiment 5, interference was suggested by significant changes in the temporal setting of key parameters of the transport component. In contrast, no such changes to the times of peak acceleration, or peak velocity, were apparent under any of the spotlighting conditions in the current experiment. Experiment 5 also demonstrated effects on grip aperture parameterization for the target fruit from having to count how many times a lateral distractor fruit of a different type was illuminated. The finding that the results for the grip aperture parameters paralleled those of Experiment 1 thus confirmed that this effect was not related to the distractor task but rather to the fact that this task was performed on the distractor fruit.

The only observable result was an augmentation in variability for the parameters of deceleration phase and movement duration under the A2, A3, and A4 conditions. The transform method of O'Brien (1981) was used to test trial-to-trial variability, and significant effects for both parameters were found (*ps* < .05).

Overall, the participants in the current experiment can be said to have had no obvious difficulties in simultaneously performing the counting task and the reach-to-grasp task on the same object. The finding of increases in variability for some parameters was under conditions where there was an

Table 7
Data (Collapsed for Fruit Type) for the Five Distractor Conditions in Experiment 6

Variable	No distractor		A1		A2		A3		A4	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initiation time (ms)	366	38	372	41	376	40	368	37	364	35
Movement duration (ms)	748	78	745	74	755	79	764	77	751	78
Transport component										
Time to peak velocity (ms)	317	32	317	34	311	34	320	33	314	33
%	42	3	42	7	41	4	42	6	41	5
Time to peak acceleration (ms)	198	22	202	20	208	21	210	25	210	23
%	26	5	27	3	27	3	27	3	28	2
Time to peak deceleration (ms)	458	44	452	48	460	50	458	53	463	50
%	61	7	61	6	61	8	60	5	61	5
Deceleration time (ms)	455	46	458	45	456	57	461	59	447	57
%	60	6	61	7	60	8	60	9	60	8
Amplitude peak velocity (mm/s)	845	90	858	88	848	90	863	89	860	88
Amplitude peak acceleration (mm/s^2)	8,101	814	8,088	805	8,077	817	8,125	813	8,150	808
Amplitude peak deceleration (mm/s^2)	8,024	799	8,081	812	8,000	802	8,110	813	8,006	803
Manipulation component										
Specification time (ms)[a]	210	22	208	23	213	24	209	23	212	22
%[a]	28	3	28	4	28	3	27	4	28	3
Time to maximum grip aperture (ms)	465	47	462	45	470	50	469	48	470	49
%	62	8	62	7	62	5	61	7	62	6
Amplitude grip aperture (mm)	83	8	85	8	85	7	84	9	84	8

Note. Intermittent spotlighting of the central fruit began before movement onset (A1), at movement onset (i.e., with release of the starting switch; A2), when the reaching arm passed a photoelectric cell 10 cm in front of the starting switch (A3), or when the arm passed another photoelectric cell 20 cm in front of the starting switch (A4).

[a] Only for cherries.

asynchrony of task onsets (A2, A3, and A4). As such, the interpretation of these modest variability changes can be linked to studies of the psychological refractory period (PRP; Broadbent, 1982; Kahneman, 1973; McLeod, 1978; see also Pashler, 1993; Pashler & Johnston, 1989). In these studies, two stimuli were presented asynchronously, and the participant was required to respond as quickly as possible to each stimulus. Early investigators, using manual responses to visual stimuli (e.g., Vince, 1949), reported a marked slowing of the second response (PRP effect) at certain interstimulus intervals.

In the current study, complex response decisions appeared to be executed simultaneously and, despite the variability augmentation, without obvious system limitations. The two tasks could be temporally grouped or coordinated to maintain the coherence of purposeful action. This finding is in line with those from previous studies that have shown that under certain conditions a motor system, such as the oculomotor system, can be triggered to operate independently of other mental activities (Pashler, Carrier, & Hoffman, 1993). Similarly, the execution of separate tasks on the same stimulus can often be accomplished without evident capacity limits (Allport, 1971; Duncan, 1984). The increase of variability found in the current experiment could reflect the temporary commitment of control processes for the asynchronous onset of the cognitive task (counting) superimposed on the ongoing function of protecting current action choices (reach to grasp).

General Discussion

The current study examined how the presence of distractors affected the kinematics of the transport and manipulation components of reaching and grasping in an ecological situation such as picking up fruits of different colors, shapes, and sizes.

It is thought that the system of selective attention directs and focuses complex perceptual information for the control of specific actions. Such selective mechanisms are fundamental for coherent behavior, and it has been proposed that an action can be disturbed when irrelevant stimuli interfere with these mechanisms (Tipper et al., 1992). However, and as Marr (1982) pointed out, attentional processes can be best understood only within the specific environment where organisms evolve and, consequently, only within the core of resultant behavioral requirements. It is believed that there are a number of advantages in using a functional movement, such as prehension in an ecological context, as an experimental model. It is a natural task, and thus the results from pure neurophysiological studies or from the more black-box behavioral studies are likely to reveal normal rather than experimentally induced central mechanisms. In the words of Marr and Nishihara (1978), it is an operation "that we as human beings perform well, fluently, reliably, and hence unconsciously" (p. 21).

Despite our everyday interactions within a three-dimensional space, previous attentional studies have largely been conducted in a two-dimensional environment and have required arbitrary responses (Haber, 1983; Tipper, 1985; Tipper & Driver, 1988). An exception is a recent work by Tipper et al. (1992) where attentional mechanisms were investigated in relation to the motor task of reaching to touch illuminated push buttons. In this study, response time to a target button was greater for those trials in which a distractor button on or near the hand trajectory was highlighted than for those trials in which there was no distractor. It was thus proposed that, at least in this case, "motor programs for the distractor are also specified in parallel" (Tipper et al., 1992, p. 903). In this view, the motor program for the distractor is considered to interfere with the planning and control mechanisms for the target motor program. A number of points can be raised in relation to this view. First, it is not clear when the inhibition, or the ignoring, of the unwanted distractor program occurs. For example, does interference occur throughout the entire movement, or is it confined only to the premovement period? Second, this view implies that there is a constant battle between unwanted and wanted outputs. If consideration is given to the interactions of daily living, it is clear that there are innumerable distractors along the motor trajectory toward, or near, a given target. The central nervous system would thus be computing a considerable load of simultaneous programs, many of which would be irrelevant. Intuitively, this strategy seems inefficient. It would also imply that a greater number of distractors should result in a greater degree of interference. Does this mean that there is an upper interference limit at which the target motor program disintegrates? Conversely, are target motor actions more efficient when they are not crowded by distractors?

The results from the current study question this parallel computation view. In short, there is little to no evidence of interference effects from distractor stimuli. Movement initiation times and kinematic parameterization for a goal-directed reach-to-grasp movement were generally not influenced by the passive presence of a neighboring stimulus that would require an alternative reach-to-grasp movement.

Experiment 1 gave the baseline kinematic profiles for the reach to grasp of four different fruits (cherry, banana, mandarin, and apple). The simple message from this experiment is that the movement parameterization for one type of fruit is different from that for another. This is not an unexpected result and is in line with previous kinematic studies of the reach-to-grasp movement for objects of different sizes (Castiello, Bennett, & Mucignat, 1993; Castiello et al., 1992; Castiello, Bennett, & Stelmach, 1993; Gentilucci et al., 1991; Jeannerod, 1981, 1984; Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987; Wing et al., 1986). At the computational level, this suggests that the motor output for one type of fruit must be selected from the range of motor outputs for the other types of fruit. Following the reasoning of Tipper et al. (1992), this would thus lead to interference effects from the unwanted fruits if a participant was presented with different pieces of fruit. In Experiments 2A–D, the existence of such effects was tested. By requiring participants to reach for and grasp, or point to, one type of fruit while presenting a distractor of the same fruit type in a different position, it can be proposed that the motor programs for the target and the distractor are the same but that movement direction differs. Assessment of movement initiation time, reaction time, and kinematic parameters from the transport (reach) and manipulation (grasp) components revealed no interference effects on the required motor output. This lack of result could not be attributed to fruit type compatibility. Even when the distractor was incompatible (i.e., of a different type), there was again no evidence of interference effects.

Null results must be treated with caution. The study of unconscious information processing has traditionally relied on participants making very fast responses. Even though the specific purpose of this study was to assess interference effects as they might occur in everyday situations, the effect of asking participants to respond as quickly as possible was also investigated. It is plausible that allowing participants to respond at their leisure might decrease the sensitivity for detecting such effects. For this reason, Experiments 2C and 2D included the assessment of both reaction time (speeded response) and movement initiation time (unspeeded response). Note that no emphasis was placed on the speed of the actual movement. This is because kinematic parameterization is significantly altered when the reach-to-grasp movement is performed at a rapid rate (Wing et al., 1986). The results for the reaction time paradigm also demonstrated no interference effects.

Neumann (1987) suggested that "the problem is how to avoid the behavioral chaos that would result from an attempt to simultaneously perform all possible actions for which sufficient causes exist" (p. 374). The findings from the current study suggest that one way to avoid this behavioral chaos is to select and execute the correct motor output while excluding alternative outputs. Selective attentional mechanisms would thus serve to specify parameterization for a particular action and to reject parameterization for irrelevant objects. Alternatively, these mechanisms may act to select only a target-centered action, other stimulus inputs being simultaneously processed but having no interference effects on this selection process (Allport, 1971; Biederman & Checkosky, 1970; Saraga & Shallice, 1973).

It is not known when and where the selection mechanisms exert their strongest effects. In Experiment 3, distractors were thus presented at different temporal points of the premovement and movement phases. Once again, evidence for interference effects was absent. Movement kinematics for the target object showed no differences according to the time at which the distractor appeared. Perceptual selection therefore appears to be quite early in relation to movement initiation. It would also appear to exert these early effects on both transport and manipulation, neither component showing interference effects. This is interesting when it is recorded that early selection was originally considered to operate in terms of stimulus location (Broadbent, 1982; Treisman, 1986). Clearly, object attributes are also processed at an early stage. In fact, with specific reference to the reach-to-grasp movement, Jeannerod (1994) also suggested that the coordinate system in relation to object attributes is defined at an early stage. Visuomotor neural pathways for spatial features of a target object (where) are thought to run in parallel with those pathways for the object attributes (what; Ungerleider & Mishkin, 1982). The finding that the output from neither of these visuomotor pathways was subject to interference effects suggests that the attentional selection for both pathways is early and that it is probably a parallel computation.

Not only does attentional selection of an action appear to be early but it also appears that the process of selection for one action has priority over selection for actions not currently needed. This effect was shown by the results from Experiment 4, where the participant was unexpectedly required to reach for and grasp an alternative piece of fruit instead of the target fruit. In some cases, the participant knew what this alternative piece of fruit was prior to movement onset for the original target fruit. In other cases, the participant became aware of this alternative only at the moment of visual perturbation. It might be supposed that the premovement awareness would result in facilitatory effects on parameterization for the perturbed movement. For example, selection of the motor output could be performed well prior to execution and consequently result in a more time efficient output. However, this was not the case. In other words, prior to movement onset, the selection was for the target (nonperturbed) fruit action. Parallel selection processing for the perturbed fruit either did not occur or occurred but with no effects on the later movement parameterization.

The attention-for-action system can be divided into two main stages. The first is a distribution phase whereby attention is nonspecifically directed on the scene in which the action will take place. As such, attention is spread over many visual stimuli, some of which are relevant and some of which are irrelevant. The second stage consists of a focusing of attentional mechanisms on the relevant stimulus. In the case of the reach-to-grasp movement, attention is specifically directed to the object to be grasped, and the appropriate motor outputs for this object's position and characteristics are retrieved.

The idea that attentional selection occurs first through a distributed stage and then through a focused stage is not new (Neumann, 1987) and received support from the results of Experiment 5. Of particular note in this latter experiment is the finding that the distractor was not passive. That is, a concurrent task distractor revealed effects that were not seen with only a concurrent stimulus distractor. Like the target of the reach-to-grasp movement, the distractor required an action (in this case, a mental action). Thus, the participant concurrently performed two tasks. For the motor task, attentional mechanisms had to be activated in relation to a reach-to-grasp movement. For the second cognitive task, attentional mechanisms had to be activated in relation to mental counting. The results indicated that the process of anchoring covert attention to another stimulus in such an active manner affected the kinematic patterning of the primary motor task.

However, if given sufficient warning, the motor output appears to compensate for the shift of covert attention to another target. This effect was demonstrated by the different results according to when the secondary task began. If this task began prior to the primary motor task, movement parameterization showed signs of compensatory strategies; that is, the acceleration phase was shortened so that greater time was allocated to the final honing deceleration phase. If the secondary task began during execution of the motor task, there were indications of some breakdown in movement coordination: Peak arm deceleration was not coupled in time with the point of maximum grip aperture. This would suggest that the covert shifting of attention to the nontarget had a clear interference effect on the ongoing movement patterning. In other words, the movement pattern that was selected was not a fixed program, mechanically executed once selected.

Of additional interest in Experiment 5 was the finding that the characteristics of the fruit to which covert attention was shifted influenced parameterization for the fruit to be grasped. For example, if the target fruit was a cherry and the distractor fruit was an apple, the maximum grip aperture for the cherry was greater than would be expected. That is, parameterization for the cherry appeared to be influenced by the parameterization for the apple. These results may relate to the ability to divide attention. It has previously been demonstrated that attention can be split on at least two foci (Castiello & Umiltá, 1990, 1992) but that this process is difficult for the attentional system (Shiffrin, 1988). In the case of Experiment 5, it is clear that attention had to be split between two stimuli: the target fruit and the distractor fruit. As a result, the motor output was affected. Attentional information gained from the distractor fruit appeared to leak into and thus influence the attention-for-motor-action pathways. It is important to note that such influences occurred only when something had to be done in relation to the distractor fruit. As shown by the results of Experiments 2, 3, and 4, the presence of a distractor without an immediate requirement for mental or motor actions had no influence on the target motor action. An exception was with the masking condition of Experiment 2C, where reaction time was greater when an apple was placed along the trajectory path. However, this effect may be related to the greater space occupied by the apple and thus the transient and probably unexpected necessity to consider how to bypass this bigger fruit.

Overall, it appears that it is not only the process of splitting attention but also that of anchoring each attentional focus to a mental–motor action that leads to cross-channel interference effects. The interesting point is the conjunction of spatial and performance aspects of attention. For example, when a person is reaching for a cherry but is forced to perform a separate counting task involving an apple, then the person's grasp aperture is distracted toward what would be required by the second object.

Experiment 6 confirmed that the disruptions to parameterization found in Experiment 5 most likely related to the active directing of covert attention to an object other than that of the action goal. When the objects for counting and action correspond, that is, covert and overt attention are directed to the same target, no interference is apparent. The act of performing two tasks on the same object does not appear to stress capacity limits (Allport, 1971; Duncan, 1984). In contrast, when some inputs are used for an action on one object and other inputs are used for an action on another object, limitations on capacity emerge. Furthermore, it could be advanced that the anchoring of attentional focus on the target area is an important prerogative for the control of action.

The focusing and anchoring of attention most probably allows an interface between object identification and the motor patterns that would be suitable for object-oriented action. The interpretation of the results of the current study may not be exclusively couched in the running off of movement parameterization. Emergence of action is also most probably subject to perceptual guidance. In the current study, the target and distractor objects were of the same living-things semantic category of fruit. This uniformity at the categorical perceptual level may also be responsible for the absence of interference for passive distractors. Clearly, there is room for further investigation of the role of the interobject categorical and functional relationships on movement organization. For example, there are examples of individuals with brain damage with recognition dysfunctions who show a response behavior disturbance according to whether visually presented objects are within living or nonliving semantic categories (Boucart & Bruyer, 1991; Laiacona, Barbarotto, & Capitani, 1993; Warrington & McCarthy, 1983; Warrington & Shallice, 1984). If perceptual categorization has an effect on movement parameterization, interference may be more evident for objects from different semantic categories or when target and distractor objects belong to noncorresponding semantic and functional categories (Castiello, Scarpa, & Bennett, 1995).

In summary, the results from the current study indicate that selectional attentional mechanisms in an ecological situation become focused on and then anchored to a specific action. Prior to this specifically directed attentional phase, a more distributed attentional phase probably acts as a window to the three-dimensional scene of action. Irrelevant stimuli, if not of immediate behavioral importance, are probably then ignored, or their influence on action systems is inhibited; that is, distractors appear to be filtered prior to the response. In any case, the selected attention-for-action channel attains priority and is relatively impermeable to passive, nonimmediate visual distractors. However, this impermeability is challenged when both the target and the distractor require active mental or motor actions.

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