Exp Brain Res (1998) 123:289–297

RESEARCH ARTICLE

Umberto Castiello

Attentional coding for three-dimensional objects and two-dimensional shapes

Differential interference effects

Received: 17 November 1997 / Accepted: 12 May 1998

Abstract The role played by the attentional mechanisms that enable dominance of relevant objects over distractor objects was investigated by measuring changes in the kinematics of the reach-to-grasp movement. Subjects reached towards three-dimensional (3D) stimuli while attention was diverted towards distracting information consisting of either two-dimensional (2D) projected shapes or 3D objects. Movement kinematics were influenced to a greater degree when a secondary task was performed involving a 3D object rather than a 2D projected shape. When the distractor was 3D, both the reaching and the grasping components were altered but, when it was 2D only, the reaching component was modified. It is suggested that, when attention is directed towards a distractor, it is associated with interference in the kinematics of the action towards the target. Further, the nature and dimensions of the distractor selectively influence the reach or the grasp component of a prehension movement.

Key words Kinematics · Selective attention · Reach to grasp · Motor control · Human

Introduction

Mechanisms of attention allow us to respond selectively to particular objects from a wide range of competing sensory stimuli. Although attention serves important perceptual functions, it is also a fundamental requirement when action is required. For example, even when there is no sensory overload from incoming parallel-processed information and no requirement for selective perception, there is still a requirement to select for action.

U. Castiello (✉)
Department of Psychology, The University of Melbourne, Australia, 3052, Parkville, Victoria, Australia

U. Castiello
Department of Clinical Neuroscience, St. Vincent's Hospital, Melbourne, Australia

Allport (1987) characterised the need for selective filtering of sensory information into the control of action. Consequently, some recent studies have described how the hand reaches towards and grasps objects in the presence of distractors within a three-dimensional (3D) space (Bonfiglioli and Castiello 1999; Castiello 1996; Chieffi et al. 1993; Jackson et al. 1995; Howard and Tipper 1997; Tipper et al. 1997).

Tipper and his coworkers (Howard and Tipper 1997; Tipper et al. 1997) demonstrated that attentional mechanisms, as revealed by distractor interference effects, access an action-based frame of reference in selective reaching. They found that, under certain conditions, the presence of the distractor could affect the trajectory of the reach to the target. For example, when the distractor was ipsilateral and close to the reaching hand, and the target far and contralateral, the midpoint of the trajectory deviated from the distractor in the contralateral direction. When the target was near and contralateral and the distractor was far and ipsilateral, the presence of the distractor tended to shift the midpoint of the trajectory towards the distractor in an ipsilateral direction. Tipper et al. (1997; Howard and Tipper 1997) concluded that both target and distractor can trigger competing reaching actions. The attentionally modulated resolution of these competing actions is played out in the kinematics of the reach to the target.

The link between selective attentional mechanisms and the control of action has also been observed in an experiment that forced a degree of covert attention to the distractor object (Castiello 1996; his experiments 5 and 6). In that study, subjects reached to grasp the target (a piece of fruit) while counting the number of times that a distractor object (another piece of fruit) was illuminated by a spotlight. Under this condition, the characteristics of the distractor influenced the kinematics of the reach-to-grasp movement. Specifically, grip aperture (the distance between the index finger and the thumb) was influenced by a lateral fruit object. If, for example, the central target was a cherry, the amplitude of peak grip aperture was greater when the distractor was an apple than when it was a banana compared with when the same target cherry was grasped without the distracting fruit. 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 size of the distractor thus appeared to intrude and affect the hand preshaping. Thus, given that the grasping features of the reach-to-grasp movement are usually associated with the intrinsic properties of the object, such as size, shape and depth, it is feasible that the volumetric properties of the distractor were encoded and eventually made available for a motor output. Interference, however, was found only when attention was directed to a lateral non-target fruit and fixation was maintained on the target object. In other words, the programming of the arm movement could be influenced by attended information in the visual field and this was independent of eye movements. Information, gained from the distractor fruit, appeared to leak into and thus influence the attention-for-motor-action pathways (Bonfiglioli and Castiello 1999).

There is further support for this conclusion from results reported by Chieffi et al. (1993), for a neglect patient. A distractor positioned on the ipsilesional side of the target shifted the reach trajectory for a middle target in the ipsilesional direction towards the distractor. Considering that patients with neglect have an attentional bias towards the ipsilesional side (Driver 1995), the evidence of interference effects found for distractors positioned on that side suggests that when distractors receive more attention interference effects during reaching are more evident.

Taken together these studies do show that under some circumstances distractor interference can be found during selective prehension (Bonfiglioli and Castiello 1999; Castiello 1996; Chieffi et al. 1993; Jackson et al. 1995; Howard and Tipper 1997; Tipper et al. 1997). Therefore it is now important to establish which specific properties of distractors will affect movement kinematics and whether the effect occurs only when the distractor comes under attentional control.

In the present paper, the distractor property that was manipulated was dimensionality (2D or 3D). In particular, the experiment reported here sought to investigate whether distractor objects presented in 2D or 3D are coded differently by attention and whether this affects the kinematics of normal reach-to-grasp movements (Jeannerod 1981, 1984). In this connection, within the literature that has investigated spatial attention Marr's model (1982) has implications for covert visuospatial attentional processes (Baylis and Driver 1993; Vecera and Farah 1994). Marr (1982) distinguished at least two classes of units based on the shape information available for representation: a surface-based unit (2D), and a volumetric unit (3D). The full primal sketch of objects, in which stimuli are coded as features (edges or lines) or surfaces, at particular spatial locations, is an example of a surface-based unit.

In the context of the present experiment, this distinction makes sense if we assume that when attention is diverted towards 2D shapes it codes for a group of features, bound to a particular location, resembling the full primal sketch proposed by Marr (1982). By contrast, when attention is diverted towards a 3D object, it codes for volumetric properties and it might be co-opted to a different degree. If this is the case, the natural question is: Are interference effects different when attention accesses 3D rather than 2D irrelevant information?

Evidence that dimensionality might be relevant for the coding of relevant and irrelevant information come also from neurophysiological studies. Recently, Shikata et al. (1996) identified a group of neurons in the posterior parietal cortex of the monkey that code for the 3D structure of objects. Further, the neuronal response varied for different object thickness. These surface orientation-selective neurons (SOS) were localised in the lateral bank of the caudal inferior parietal sulcus, in the dorsal stream of the cortical spatial visual pathway. Thus, these finding suggest, in contrast with the idea that object vision is a "ventral" activity (Ungerleider and Mishkin 1982), that the dorsal stream might be involved also in the coding of 3D structure of objects. This hypothesis is consistent with Milner and Goodale's (1992) idea that the dorsal pathway is important for the control of actions. Consequently the activity of the SOS neurons may be useful for the visual guidance of hand movements particularly for the adjustments of the hand to the surface of an object for grasping and manipulation.

The relationship between a differential coding of objects and prehensile activities was also highlighted by Brenner and Smeets (1996). They showed that grip aperture scaling was based upon a simple analysis of object shape and surface properties, whereas grip force scaling was based upon a more complete analysis of an object's volumetric properties.

In summary, it could be inferred that different objects in the visual field might compete in terms of their structure or dimension as well as other features such as position, orientation and colour (Cohen and Shoup 1997). A projected 2D shape might compete in terms of its position in space and size, but not on the basis of its graspable attributes. In this respect, a 3D distractor would certainly be more relevant. If this is the case, interference in movement kinematics, to say, for a reach-to-grasp movement, would affect selectively different segments of the action depending whether the distractor is 2D or 3D. For example, the grasp component should be affected only when a 3D distractor is presented. This is because a 2D projected shape does not have graspable attributes to enhance a parallel intended-but-not-executed grasping program.

In the present experiment, subjects were required to reach towards and grasp a 3D target. Further, and simultaneously with the reach-to-grasp task, subjects were required to detect a stimulus (dot) presented in cued and uncued positions (Posner et al. 1980) within the 3D object or the 2D shape distractor. If the stimulus appeared in the same position as the cue, trials were defined as "valid". If the stimulus appeared in an uncued position, trials were defined as “invalid”. When the stimulus was presented, subjects had to say “tah” as fast as possible. Vocal reaction time (VRT) was measured. It was expected that VRT for valid trials would be faster than VRT for invalid trials (Posner et al. 1980). Performance on the concurrent orienting task would provide an index of the extent to which attention was oriented towards the distractor.

Materials and methods

Subjects

Twenty students (10 women and 10 men, aged 20–32 years) participated in the experiment. All were right-handed (Edinburgh Inventory; Oldfield 1971), reported normal or corrected-to-normal vision, and were naive as to the purpose of the experiment. They attended one experimental session of 1 h.

Apparatus

In a dark room, the target object, an apple, was positioned 30 cm in front of the subject’s midline. The 3D distractor object was a cup (~9×8 cm) or a box opened at the top (9×8 cm; see Fig. 1A). The 2D distractors were irregular and regular projected shapes (for an example, see Figs. 1B, 2). All the 2D shapes were projected into an area of 9×8 cm. Both types of distractor were presented in the *z*-axis at 30° from the centroid of each distractor to the right or left of the target. In the case of the more elongated distractor (banana), the experimenter ensured that it was always positioned at the same orientation. The two distractor/task conditions (2D, 3D) were compared with three control conditions. In the first control condition, the distractor was not presented (C1). In the second control condition, the distractor was presented before movement initiation and no secondary task had to be performed (C2). In the third control condition, the distractor was not presented but the cue and the stimulus could still appear (C3). In order to avoid anticipatory responses, catch trials (10%), where the cue appeared but the stimulus did not appear, were also included. The presentation of the trials for the five experimental conditions was counterbalanced within subjects.

Two of the projected shapes were fruits, thus in some cases the target and the distractor pertain to different semantic categories. In order to avoid semantic confounding, analyses compared the trials in which the target and the distractor were of different semantic categories with those in which the target and the distractor were the same semantic category. Results showed that there were no differences for the dependent measures of interest.

Procedure

Prior to each trial, the subject’s right hand was on a pressure-sensitive switch positioned 20 cm in front of the subject’s midline. Subjects were required to grasp the apple while maintaining eye gaze on it and to concurrently detect stimuli presented on the distractor itself (Fig. 1). There were 96 trials (12 for each condition). On all trials, the target was always visible and the distractor was illuminated by a spotlight 500 ms before the acoustic signal (880 Hz; duration 200 ms) for movement initiation was sounded. One hundred milliseconds after the acoustic signal, a white cue (82 cd/m^2, duration 200–300 ms) was projected on different positions of the 3D or the 2D distractor. One hundred milliseconds after the white cue disappeared, a red stimulus (16 cd/m^2) appeared. The cup or the box were oriented in such a way that the white cue and the red stimulus could be projected on any of the different faces (see Fig. 1A). A modified version of the Posner paradigm (Posner et al. 1980), in which the stimulus could appear in a cued or un-

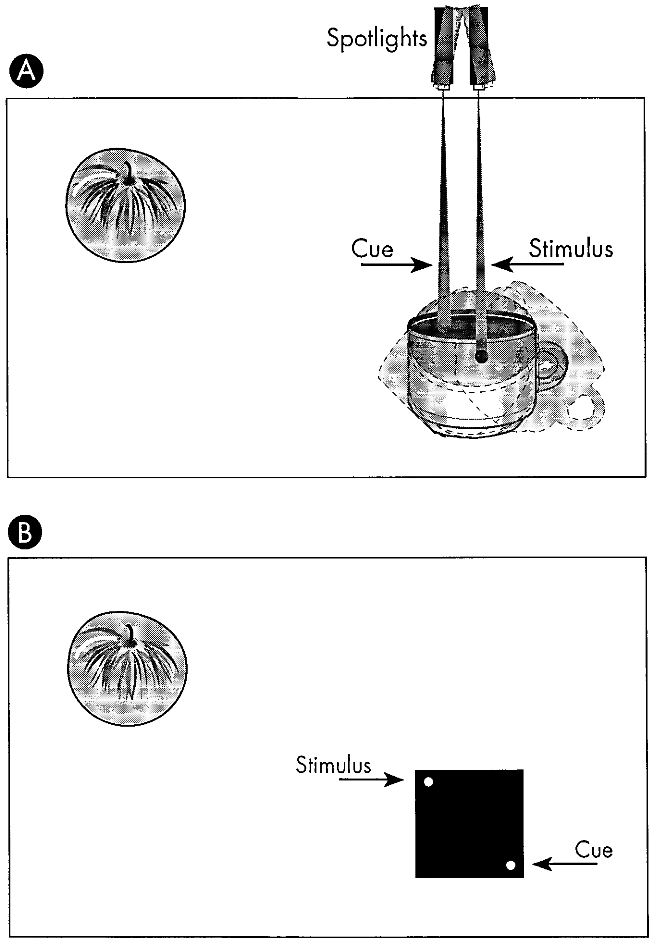

Fig. 1A, B Experimental setup. **A** Central target presented with the 3D object. **B** Central target presented with an example of the regular 2D shapes

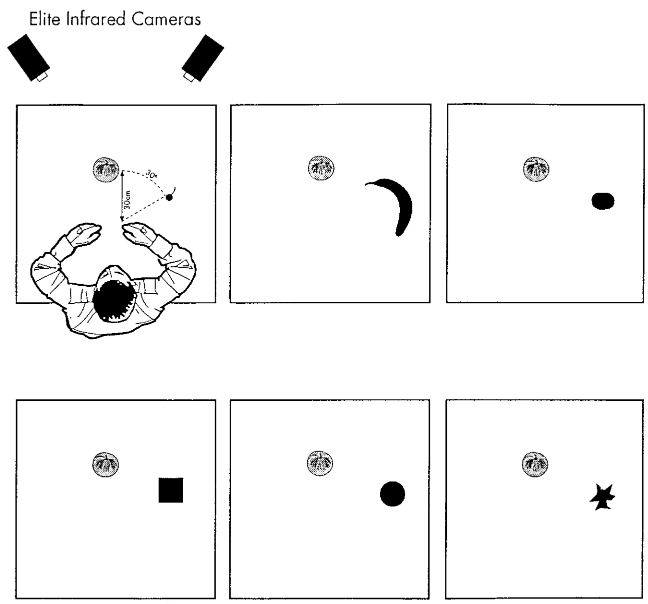

Fig. 2 Example of the experimental conditions where the target is presented with the two-dimensional projected shapes

cued position on the objects, was employed. If the stimulus appeared in the same position as the cue, trials were defined as valid. If the stimulus appeared in an uncued position, trials were defined as invalid. Only 20% of the trials were invalid. Valid and invalid trials for the 3D distractor objects could be of two types, “front face” or “back face”. In the front face valid trials the cue and the stimulus appeared on the same angles of the front face. In the back face valid trials the cue and the stimulus appeared on the same angles of the back face. In the front face invalid trials, the cue and the stimulus appeared on different angles of the front face. In the back face invalid trials, the cue appeared on different angles of the front face and the stimulus appeared on different angles of the back face. The invalid condition where the cue and the stimulus appeared on different angles of the back face was not considered. The 80:20% ratio applies only for the trials where the secondary task had to be performed (2D, 3D and C3). When the stimulus was presented, subjects had to say “tah” as fast as possible (Castiello and Jeannerod 1991; Castiello et al. 1991). VRT was measured. From the difference in VRT between valid and invalid trials, it was possible to measure the cost of orienting attention towards the position where the stimulus did not appear. In order to avoid the ambiguous effect that often characterises neutral trials, these type of trials were not included (Jonides and Mack, 1984). Please note that, in 4% of the total number of trials, the stimulus within the 3D distractor appeared after the target was already grasped. These trials were discarded and replaced with trials where the reach-to-grasp action was completed after the detection task was performed. In 2% of the total number of trials, these two moments were almost coincident.

Recording techniques

Reflective passive markers (0.25 cm diameter) were attached to the wrist, the index finger and the thumb. Movements were recorded with the ELITE motion analysis system. This 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 spatial error measured from stationary and moving stimuli was 0.4 mm. Coordinates of the markers were reconstructed with an accuracy of 1/3000 of the field of view and sent to a host computer.

Horizontal and vertical eye movements were recorded with an infrared corneal reflection system (sampling frequency 120 Hz.). Trials in which eye movement exceeded 1° of visual angle (vertical and horizontal) were replaced.

Data processing and analysis

The ELIGRASP (BTS 1994) software package was used to derive 3D reconstruction of the marker positions. The data were then filtered using a finite impulse response (FIR) linear filter – transition band of 1 Hz (sharpening variable 2; D’Amico and Ferrigno 1990 1992). The cut-off frequency was 10 Hz. The reach component was assessed by analysing the trajectory, velocity and acceleration profiles of the wrist marker. The grasp component was assessed by analysing the trajectory of each of the hand markers and the distance between these two markers. Movement initiation time, so-called because no emphasis was placed on a rapid response, was taken from release of the starting switch. Onset of the grasp component was taken as the time at which the hand began to open; that is when the distance between the index finger and thumb markers was no longer constant and showed increments of more than 0.4 mm. The end of the movement was taken as the time when the fingers closed on the target and there was no further change in the distance between the index finger and thumb. Movement duration was taken as the time between movement onset and the end of the action. The period following this, in which the target was lifted, was not assessed. Absolute temporal values obtained were expressed also as a percentage of movement duration (e.g. the absolute time at which peak velocity occurred was expressed as a percentage of movement duration). The dependent variables were: (a) initiation time; (b) movement duration; (c) reach component parameters: times to peak velocity, peak acceleration, peak deceleration of the wrist marker and the amplitudes of these peaks (amplitude peak velocity, amplitude peak acceleration and amplitude peak deceleration, respectively); and (d) grasp component parameters: time to maximum grip aperture, amplitude of maximum finger aperture and speed of finger aperture.

Results

The means, standard deviations (SDs) and results from the statistical analysis are presented in Table 1. Each dependent kinematics variables was analysed with an analysis of variance (ANOVA) with Type of trials (2D, 3D front face, 3D back face, C1, C2, C3) as a within-subjects factor. Post hoc comparisons were conducted on the means of interest using the Newman-Keuls procedure (alpha level 0.05). VRTs were analysed with an ANOVA with Type of trials (2D, 3D front face, 3D back face, C3) and Condition (valid and invalid) as a within-subjects factors.

The main factors Condition and Type of trials were significant (Condition: $F_{5,95}$=21.04, P<0.0001; Type of trials: $F_{1,19}$=31.12, P<0.0001). VRTs were significantly faster for valid than for invalid trials (392 ms vs 432 ms). The interaction between the factors Condition and Type of trials was significant ($F_{1,19}$=9.07, P<0.001). VRTs for valid and invalid trials were found to be faster for stimuli presented within the 2D distractor than within the front face of the 3D distractor or within the back face of the 3D distractor (valid: 377, 392 and 409 ms; invalid trials: 401, 430, 466 ms, respectively; see Fig. 3). Further, VRTs were significantly faster for stimuli presented in the front than in the back face of the 3D object distractor (404 ms vs 421 ms). When the distractor was not displayed (C3), VRTs for valid and invalid trials were not significantly different (375 ms and 384 ms, respectively). This latter result is taken to indicate that when the distractor is not present the subjects have difficulty maintaining attention on a specific position. Without the “anchor” effect provided by the distractor, it may be easier to distribute attention upon a larger portion of space that still enables detection of the target, disregarding the cue. One possibility for reduced cue effectiveness was suggested by a set of studies (Castiello and Umiltá 1992; Hughes and Zimba 1985; Zimba and Hughes 1987) which found that, in the absence of display markers to indicate the location of potential targets, the effect of spatial cueing on reaction time was markedly attenuated.

The “cost” was also analysed, i.e. the difference between VRT for stimuli presented in cued (valid) and uncued (invalid) positions within the 3D objects or the 2D shapes (3D front face, 3D back face, 2D). The cost in milliseconds was greater for the back than the front face of the 3D distractor or the 2D shapes ($F_{2,38}$=6.07, P<0.05, 57, 38 and 24 ms for 3D back face, 3D front face and 2D, respectively). These results confirm previous findings regarding the distribution of attention in 3D

Table 1 Initiation time, movement duration and kinematic values for the different task conditions (SD in parentheses)

	C1	C2	C3	2D	3D frontface	3D backface	Statistical values
Initiation time (ms)	341* (32)	338* (30)	342* (35)	355 (33)	385 (42)	400 (40)	$F_{5,95}$=18.08 P<0.0001
Movement duration (ms)	688* (73)	700* (85)	702* (67)	699* (72)	754 (89)	838 (85)	$F_{5,95}$=32.04 P<0.0001
Reach component							
Time to peak velocity (ms)	275* (32)	270* (30)	273* (29)	298 (32)	354 (35)	419 (52)	$F_{5,95}$=21.01 P<0.0001
Time to peak velocity (%)	39* (4)	38* (5)	38* (4)	42 (4)	46 (5)	50 (5)	$F_{5,95}$=10.11 P<0.001
Time to peak acceleration (ms)	212* (25)	210* (22)	213* (27)	225 (28)	253 (26)	289 (32)	$F_{5,95}$=8.97 P<0.001
Time to peak acceleration (%)	30* (3)	30* (4)	30* (4)	32 (4)	33 (3)	34 (5)	n.s.
Time to peak deceleration (ms)	410* (51)	414* (49)	418* (40)	435 (46)	498 (53)	583 (67)	$F_{5,95}$=32.22 P<0.0001
Time to peak deceleration (%)	59* (6)	59* (6)	60* (6)	62 (6)	66 (7)	69 (8)	$F_{5,95}$=13.26 P<0.001
Amplitude peak velocity (mm/s)	888* (92)	900* (99)	876* (90)	888* (87)	801 (83)	702 (77)	$F_{5,95}$=9.56 P<0.001
Amplitude peak acceleration (mm/s^2)	8212* (841)	8314* (832)	8289* (841)	8076 (807)	7128 (722)	6848 (695)	$F_{5,95}$=16.22 P<0.001
Amplitude peak deceleration (mm/s^2)	7045* (735)	7112* (713)	7099* (821)	6514 (698)	5421 (647)	5167 (714)	$F_{5,95}$=25.78 P<0.0001
Grasp component							
Time to maximum grip aperture (ms)	481* (52)	478* (50)	478* (52)	477* (53)	512 (52)	603 (69)	$F_{5,95}$=19.31 P<0.0001
Time to maximum grip aperture (%)	69* (8)	68* (7)	68* (8)	68* (7)	65 (7)	71 (8)	$F_{5,95}$=18.22 P<0.0001
Rate of finger aperture (mm/s)	536* (61)	498* (51)	500* (59)	522* (52)	343 (36)	267 (31)	$F_{5,95}$=15.13 P<0.001

Nonsignificant differences were found between C1, C2 and C3. *The means that do not differ (Newman-Keuls)

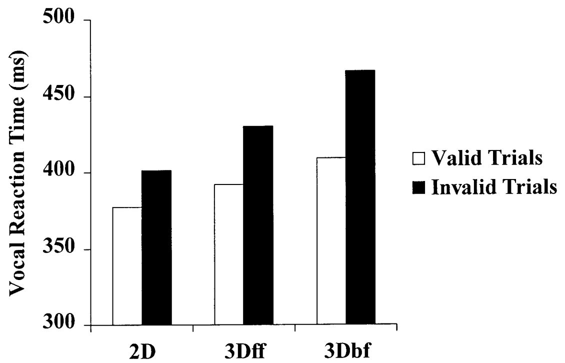

Fig. 3 Mean reaction times for valid and invalid trials for stimuli presented within the 2D projected shape, within the front face (*ff*) of the 3D distractor and the back face (*bf*) of the 3D distractor

space, where longer reaction times occurred when the subject shifted attention in depth (Bennett and Castiello 1996; Downing and Pinker 1985; Gawryszewski et al. 1987). Importantly this difference in VRTs for valid and invalid trials suggests that the subjects in the experiment were directing attention covertly towards distractors.

The results also demonstrate that a greater cost corresponded to a greater interference in movement kinematics. Interference effects were larger when, in order to detect the stimulus, covert attention had to move between the different faces of the 3D object than when attention traversed one surface of a 3D object, or over a 2D shape distractor. For example, initiation time and movement duration were longer for 3D back face, 3D front face, 2D and the different control conditions (C1, C2 and C3), respectively (see Table 1, Fig. 4). The kinematics of the reaching component were also significantly delayed when the subjects performed the secondary task within a 3D object than within a 2D shape. As an example, time to peak velocity was delayed when the secondary task was performed with the 3D distractor compared with the 2D projected shape distractor (398 ms vs 298 ms). Figure 5 shows these differences for times to peak velocity, acceleration and deceleration (for the values, refer to Table 1). The nature of the secondary task also influenced the amplitudes of peak velocity, acceleration and deceleration of the arm. They were lower when the secondary task had to be performed within the 3D object than within the 2D projected shape (see Table 1). For the grasp compo-

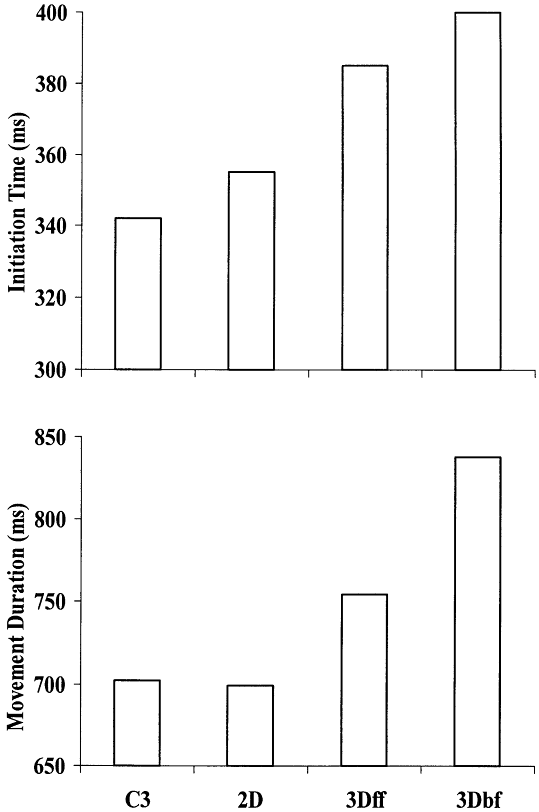

Fig. 4 Differential level of interference for initiation time (*upper panel*) and movement duration (*lower panel*) for all distractors' conditions versus C3 (*ff* front face, *bf* back face)

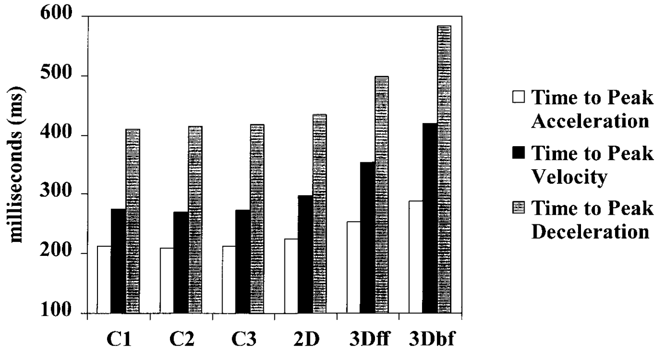

Fig. 5 Differential level of interference for times to peak velocity acceleration and deceleration for the three distractor conditions (C1, C2 and C3), when the secondary task had to be performed within the front face (*ff*) of the 3D distractor, the back face (*bf*) of the 3D distractor or the 2D projected shapes

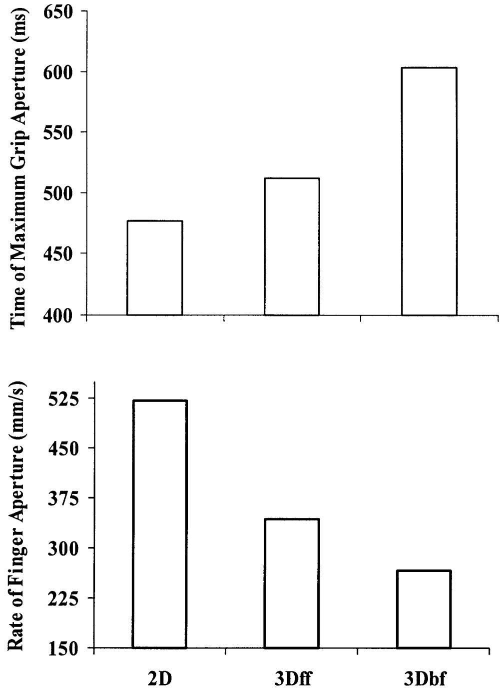

Fig. 6 Differential level of interference for time of maximum grip aperture (*upper panel*) and rate of finger aperture (*lower panel*) for the 3D and the 2D distractor (*ff* front face, *bf* back face)

nent, the kinematics were delayed to a greater extent for the 3D object than for the 2D projected shape (see Table 1, Fig. 6). In absolute terms, time to maximum grip aperture was reached later when the secondary task was performed within the back face of the 3D distractor than within the front face of the 3D distractor or the 2D distractor. Similarly, the rate of finger aperture was significantly slower when the secondary task was performed within the back face of the 3D distractor than within the front face of the 3D distractor or the 2D distractor. For this latter parameter, no difference between the 2D distractor and the control conditions was found.

A possible problem related to the use of fruit stimuli may be the variability in movement kinematics due to the irregularities in shape, size and color. Of course this could be a problem if the same fruits are not utilised for all the subjects. However, during the 10 days of experimentation, only two sets of stimuli were used. These two sets were very similar. Further, and as mentioned above, target and distractors were presented in the same position and orientation for all subjects. Nevertheless, to have some measure of the level of variability, some crucial parameters that may have been affected by differences in size were analysed comparing the same target/distractor combinations between subjects that used different sets of fruits, e.g. time and amplitude of maximum grip aperture. Time and amplitude of maximum finger aperture did not differ for any of the target/3D distractor combinations.

As a final point in this section, no differences for any of the dependent measures were found using post hoc comparisons between the three control conditions (see Table 1). Thus, it may be advanced that if C1 (no distractor) does not differ from C2 (no attention instruction) or C3 (no distractor but attend to secondary task) the attentional manipulation did not work. However, it is important to remember that in C3 no differences between valid and invalid were found. In the absence of display markers to indicate the location of potential targets, the effect of spatial cueing on reaction time was markedly attenuated. Similarly, the lack of differences between the three control conditions in all the other dependent measures may be related to the fact that in C3 the attentional task was performed in the absence of the distractor object. When the distractor was not present, the task of responding to a flash of light, can be performed without affecting the movement to the target in a similar fashion as for C1 and C2.

In summary, these results suggest that shifting attention to different faces of the 3D distractor produced different effects on the kinematics to a target and interference appeared to be selectively channeled. When the distractor was 3D, both the reach and the grasp components were affected; the 3D object distractor seemed to compete in terms of the grasping action it required and its volumetric properties. When the distractor was a 2D shape, it was mainly the reaching component that was affected. This shape was not considered as a graspable object or as having functional graspable units; therefore competition appeared to be resolved only at reaching component level.

Discussion

The aim of the present study was to investigate whether distractor objects presented in 2D or 3D are coded differently by attention and whether this affects the kinematics of normal reach-to-grasp movements. Subjects reached for a 3D object while distracting information was presented. When attention was directed to it, the presence of a distractor object interfered with the initiation, duration and kinematics of the reach-to-grasp movement towards the target. When attention was not directed to it, however, no such interference effects were observed. Furthermore, interference effects were greater with 3D distractors compared with 2D projected shapes of equivalent size. From Marr's theory (1982), it could be inferred that the attentional time course would be affected by structure. Marr (1982) proposed that there are three stages involved in computation of an object. The primal sketch is followed by a $2^1/_2$-dimension (D) sketch, and by full 3D depiction of the object. The (first) primal sketch involves a grouping of rough boundaries of objects. The (second) $2^1/_2$-D sketch involves the specification of surfaces of objects. The (third) full 3D depiction is achieved after object specific knowledge. In the $2^1/_2$-D sketch stage, an observer would only have access to a 2D representation of the object. Yet further along, an observer would have access to a full 3D representation. This infers that the time course of processing is linked to the computation of structure. As such, it would be expected that the more complex the object, the longer it would be the attentional time course. In the present experiment when comparing VRTs for trial types (valid front face and valid back face, invalid front face and invalid back face), an interesting pattern emerged. Valid are faster than invalid and valid and invalid for the front face are faster than valid and invalid for the different face. This cue validity effect could be regarded as a surprising result given that both the cued location and the target location are always very close to each other, even when invalid. However, recent studies using a Posner-type paradigm were able to demonstrate that the normal cost-benefit function to stimuli in expected and unexpected locations applied when attention was allocated within a 3D object smaller to that used in the present experiment (Bennett and Castiello 1996; Umiltá et al. 1995). Observers took longer to orient attention within different faces of the 3D distractor, indicating that structural factors were influencing the attentional performance. The depth cues present in the 3D distractor force attention to scan the depth plane. This suggests that structure determine an attentional time course that is longer for computing a 3D object than a 2D projected shape. Further, the VRT data are highly correlated with the interference data. Conditions associated with slower VRTs are also the ones in which kinematics show more disruption. Interference effects on movement kinematics were much greater when covert attention is captured by a 3D object than a 2D shape distractor. Yantis and Jonides (1984) have proposed that visual onsets capture attention because they coincide with the appearance of a perceptual object. When a new object appears in the visual field, it is necessary to create a new perceptual representation of it and attention is typically directed towards it. If it can be assumed that in the present experiment the sudden appearance of the distractor originated a perceptual representation, a conflict between target and distractor representations may have emerged. The current results seem to confirm this hypothesis. They demonstrate a conflict between attributes of the distractor and those of the target. Two patterns of interference were observed. First, when the distractor was a 3D object, the kinematics of both the reach and the grasp components were influenced. Second, when the distractor was a 2D shape, conflict was confined to the reaching component. This difference can be explained in terms of graspable attributes. The projected 2D shape, although having a size, did not have graspable attributes, thus it is unlikely that a parallel grasping plan is initiated. In contrast, even if the 2D projected shapes did not have graspable attributes, they were still located in a position that differs from the location occupied by the target. Thus, parallel computation can occur for different locations, the location for the target and the location for the distractor. In contrast, the 3D distractor not only was located in a position that differed from the location occupied by the target but also possesses graspable attributes. The latter factor might be the determinant that enhanced the computation of a parallel grasping plan that "competed" with that for the target. The result was that conflict emerged at the level of both the reach and the grasp components. According to the multiple resources view proposed by Allport (1980), many sources of conflict or competition depend on the particular processing systems that tasks require in common. In the present context, competition might be sensitive to the attributes of irrelevant objects that match those of the object relevant to the end goal. In the present study, the 3D distractors required a different type grasping action than the target object. The parallel computation for different grasping actions, one for the target and one for the attended distractor, maybe at the origin of the changes noticed for the kinematics of the action directed to the target (Castiello 1996; Gentilucci et al. 1991).

Klatzky et al. (1987) demonstrated that knowledge about the object specifies the patterns of hand contact. They distinguished between hand-shape representations associated with objects in memory and show how such representations are related to the structural and functional properties of objects. In light of this body of data, it is suggested that conflicts emerge when the distractor and target objects require different prehensile patterns, in order to be grasped or manipulated. Kinematic planning and functional properties for the irrelevant distractor object are alerted and interfere with kinematic planning and functional properties activated and executed for the target object. In other words, distractors automatically activate their responses without the subject's intention to act (Lhermitte 1983). Thus, different objects in a visual scene can evoke the parallel implementation of actions (Eriksen 1995; Goldberg and Segraves 1987; Tipper et al. 1997). If more than one motor pattern is kept active at a time this parallel activation determines mutual interference (Duncan 1996).

At this point the natural question is how the system overcomes the interference caused by competing messages? Various models have been advanced in the literature to account for selection (Houghton and Tipper 1996; Tipper et al. 1994). According to these models, at a certain point between sensorial input and motor output, target and distractor objects (or some of their features) compete for the control of behaviour. In order to avoid the interference effects of the distractor on the performance, it is assumed that the relevant information is selected and the irrelevant information is inhibited from further processing. The competition between these different streams of information is supposed to be biased towards the information relevant for the task that has to be accomplished. In the present study, the subject knows in advance what kind of target has to be attended to, thus priority may be assigned to the target. The result is that the interference effects found in the present experiments do not result in a complete breakdown in movement such as missing the target. They only produce a slowness and a reorganization of the kinematic parameterization of the movement. However, what is found in the present study is that only when spatial attention is directed to the distractor is perception of irrelevant information coupled to action (Bonfiglioli and Castiello 1999; Castiello 1996). Thus, any argument regarding interference is confined to the level of salience reached by distractor, when the distractor is presented.

Conclusions

The results obtained in the present study are largely compatible with theories that suggest predominant role for attention in shaping behaviour through influencing motor output (Allport 1987; Cohen and Shoup 1997). In addition these findings suggest that attention is necessary for the structural description of unattended objects.

Attention can be similarly oriented towards different types of "objects" (2D and 3D), and differences in kinematics clearly depend on the focus of attention. When attention is attracted towards a 2D shape, it codes for features that remain at a low level of processing. However, when attention is attracted towards a 3D object, it codes for the volumetric features of that object. This difference in the level of processing reflects on the kinematics of the goal-directed action. Interference is much greater for a 3D object than for a 2D shape. In other words, for 2D shapes, information is deemed irrelevant at an earlier stage than for 3D objects. In the latter case, a volumetric exploration cannot be avoided. Consequently interference effects on the action in progress are related to the extent to which the distractor competes with the target for computational resources, analysis, and control. Spatial selective attention is thus proposed as a neuromodulator for the computational passage from 2D to 3D modes for the acquisition of information, analysis and control of action. When it is oriented towards irrelevant stimuli it codes for the volumetric features, and it is this geometric status that determines the access of such stimuli to the appropriate stage of computation.

In conclusion, this study identifies new conditions determining the disruption of kinematics for normal selective movements in response to irrelevant information. The identification of these factors is a critical step in the development of useful measures for studying selection-for-action, object representation and selective attentional mechanisms. Whether or not visual information from more objects can be attended to simultaneously, is not only contingent on information load, but it also depends on functional and structural factors of the stimulus, such as depth structure.

Acknowledgements This research was sponsored by the Australian Research Council and by the National Health and Medical Research Council of Australia. Helen Chambers and Rachael Sanders are thanked for helping in all the aspects of this research. Ross Day, Patrick Haggard, Jason Mattingley and Ada Kritikos are warmly thanked for their useful comments on the previous versions of this manuscript.

References

Allport A (1980) Attention and performance. In: Claxton G (ed) Cognitive psychology: new directions. Routledge & Kegan Paul, London, pp 112–153

Allport A (1987) Selection for action: Some behavioral and neurophysiological considerations of attention and action. In: Heuer H, Sanders AT (eds) Perspectives on perception and action. Erlbaum, Hillsdale, NJ, pp 395–419

Baylis GC, Driver J (1993) Visual attention and objects: evidence for hierarchical coding of location. J Exp Psychol Hum Percept Perform 19:451–470

Bennett KMB, Castiello U (1996) Three-dimensional covert attentional functions in Parkinson's disease subjects. Exp Brain Res 112:277–288

Bonfiglioli C, Castiello U (1999) Selective interference effects during prehension movements. Percept Psychophys (in press)

Brenner E, Smeets JB J (1996) Size illusion influences how we lift but not how we grasp an object. Exp Brain Res 111:473–476

Castiello U (1996) Grasping a fruit: selection for action. J Exp Psychol Hum Percept Perform 22:582–603

Castiello U, Jeannerod M (1991) Measuring time to awareness. Neuroreport 2:797–800

Castiello U, Umiltá C (1992) Splitting attentional focus. J Exp Psychol Hum Percept Perform 18:837–848

Castiello U, Paulignan Y, Jeannerod M (1991) Temporal dissociation of motor responses and subject awareness. Brain 114: 2639–2655

Chieffi S, Gentilucci M, Allport A, Sasso E, Rizzolatti G (1993) Study of selective reaching and grasping in a patient with unilateral parietal lesion. Brain 116:1119–1137

Cohen A, Shoup R (1997) Perceptual dimensional constraints in response selection processes. Cogn Psychol 32:128–181

D'Amico M, Ferrigno G (1990) Technique for the evaluation of derivatives from noisy biomechanical displacement data using a model-based bandwidth-selection procedure. Med Biol Eng Comp 28:407–415

D'Amico M, Ferrigno G (1992) Comparison between the more recent techniques for smoothing and derivative assessment in biomechanics. Med Biol Eng Comp 30:193–204

Downing CJ, Pinker S (1985) The spatial structure of visual attention. Erlbaum, Hillsdale, NJ

Driver J (1995) Object segmentation and visual neglect. Behav Brain Res 71:135–146

Duncan J (1996) Cooperating brain systems in selective perception and action. In: Innui T, McClelland JL (eds) Attention and performance XVI . MIT Press, Cambridge, Mass, pp 549–578

Eriksen CW (1995) The flankers task and response competition: a useful tool for investigation a variety of cognitive problems. Vis Cogn 2:101–118

Gawryszewski LDG, Riggio L, Rizzolatti G, Umiltá C (1987) Movements of attention in the three dimensions and the meaning of "neutral" cues. Neuropsychologia 25:19–29

Gentilucci M, Castiello U, Corradini ML, Scarpa M, Umiltá C, Rizzolatti G (1991) Influence of different types of grasping on the transport component of prehension movement. Neuropsychologia 29:361–378

Goldberg ME, Segraves MA (1987) Visuospatial and motor attention in the monkey. Neuropsychologia 25:107–18

Goodale MA, Milner AD (1992) Separate visual pathways for perception and action. Trends Neurosci 15:20–25

Houghton G, Tipper SP (1996) Inhibitory mechanisms of neural and cognitive control:applications to selective attention and sequential action. Brain Cogn 30:20–43

Howard LA, Tipper SP (1997) Hand deviations away from visual cues:indirect evidence for inhibition. Exp Brain Res 113: 144–152

Hughes HC, Zimba LD (1985) Spatial maps of directed visual attention. J Exp Psychol Hum Percept Perform 11:409–430

Jackson SR, Jackson GM, Rosicky J (1995) Are non-relevant objects represented in working memory? The effect of non-target objects on reach and grasp kinematics. Exp Brain Res 102: 519–530

Jeannerod M (1981) Intersegmental coordination during reaching at natural visual objects. In: Long J, Baddeley A (eds) Attention and performance IX Erlbaum, Hillsdate, NJ, pp 153–169

Jeannerod M (1984) The timing of natural prehension movements. J Mot Behav 16:235–254

Jonides J, Mack R (1984) On the cost and benefit of cost and benefit. Psychol Bull 96:29–44

Klatzky RL, McCloskey B, Doherty S, Pellegrino J, Smith T (1987) Knowledge about hand shaping and knowledge about objects. J Mot Behav 19:187–213

Lhermitte F (1983) "Utilization behavior", and its relation to lesions of the frontal lobes. Brain 106:237–255

Marr D (1982) Vision. Freeman, San Francisco

Oldfield RC (1971) The assessment and analysis of handedness:the Edinburgh inventory. Neuropsychologia 9:97–113

Posner MI, Snyder CR, Davidson BJ (1980) Attention and the detection of signals. J Exp Pychol 109:160–74

Shikata S, Tanaka Y, Nakamura H, Taira M, Sakata H (1996) Selectivity of the parietal visual neurones in 3D orientation of surface of stereoscopic stimuli. Neuroreport 7:2389–2394

Tipper SP, Weaver B, Houghton G (1994) Behavioural goals determine inhibitory mechanisms of selective attention. Q J Exp Psychol 47A:809–840

Tipper SP, Howard LA, Jackson SR (1997) Selective reaching to grasp:evidence for distractor interference effects. Vis Cogn 4: 1–38

Umiltà C, Castiello U, Fontana M, Vestri A (1995) Object-centred orienting of attention. Visual Cogn 2:165–181

Ungerleider LG, Mishkin M (1982) Two cortical visual systems. In: Ingle DJ, Goodale MA, Mansfield RJW (eds), Analysis of visual behavior. MIT Press, Cambridge, Mass, pp 549–586

Vecera, SP, Farah MJ (1994) Does visual attention select objects or locations? J Exp Psychol Hum Percept Perform 123:146–60

Zimba LD, Hughes HC (1987) Distractor-target interactions during directed visual attention. Spat Vis 2:117–149