PERGAMON

Neuropsychologia 37 (1999) 857–868

NEUROPSYCHOLOGIA

Semantic category interference effects upon the reach-to-grasp movement

Caroline Jervis[a], Kerry Bennett[b], Joyce Thomas[b], Suryani Lim[a], Umberto Castiello[a,]*

[a] *Department of Psychology, The University of Melbourne and Department of Clinical Neuroscience, St Vincent's Hospital, Melbourne, Australia*
[b] *Faculty of Health Science, La Trobe University and Department of Clinical Neuroscience, St Vincent's Hospital, Melbourne, Australia*

Received 12 May 1998; accepted 15 September 1998

Abstract

In the present study the kinematics of the reach-to-grasp movement towards a target object in the presence of distractors was investigated. Three experiments were conducted. In the first experiment, there were three conditions, (a) the target alone, (b) the target presented with a distractor object that was semantically similar to the target and (c) the target presented with a distractor object that was semantically different from the target. The same conditions were repeated for the second experiment but the size of the distractors were also manipulated. For the third experiment the target was presented with a distractor object that was semantically different from the target but similar in shape. In the first experiment interference effects were observed in kinematic parameters of the grasp, but not for the reach component when the target and the distractor were semantically different. In the second and the third experiment, similar results were found. Results are discussed in terms of conflicting processing between objects pertaining to different semantic categories.

Keywords: Reach-to-grasp; Humans; Semantic categorisation; Kinematics

1. Introduction

There is a seeming simplicity in human prehension. Both gross and precise manipulations are a part of the normal human's repertoire of motor output, the former requiring the whole hand, and the latter utilising the tip of the thumb and forefinger alone. One only has to picture the differences in grasp between, say, a grapefruit, and a grain of rice, to appreciate the wide range of variation in prehension available to the human hand [29].

Although research has established the component parts of the reach-to-grasp movement, and how these relate to different visual processing channels [17–19], research has begun only recently to test how subjects reach and select one object from among other objects [4, 5, 8, 14, 15, 37]. The presentation of more than one object in the visual field provides an opportunity to assess whether visual information from the to-be-ignored object, or distractor, has any effect on the kinematic parameters of either the reach, or the grasp component of a prehension movement.

Tipper and his colleagues [37] argued that objects which must be ignored are neurally represented and compete for control of motor output. They postulated that it was the volumetric space taken up by these distractor objects, that was the factor that led to competition in the motor control of action. The method employed by Tipper et al. [37] involved four positions on the working surface at which the experimental objects (two wooden cubes, one green, one blue) could be positioned. A cue signaled the target and the start of the movement. A speeded response was required and no object information was available prior to movement onset. Results showed that near targets may be perceived as obstacles when the hand reaches toward a far target. Tipper et al. [37] suggested that distractors may lead to interference effects to the kinematics of the reach.

In goal-oriented tasks, where a non-speeded response was required, distractor interference effects were not observed [5, 8, 15]. Chieffi et al. [8] asked subjects to reach and grasp a target object in the presence or absence of distractor objects. The experimental objects were same or different sized horizontal cylinders (length 3 cm, diameter 1 or 3 cm). The target was red, the distractors green or blue. It was hypothesised that if the target and distractor were identical in size, selection of the reach component alone was necessary. If the target and distractor

* Corresponding author. Department of Psychology, The University of Melbourne, Parkville, 3052 Vic, Australia. E-mail: u.castiello@psych.unimelb.edu.au

0028-3932/99/$ - see front matter
PII: S0028-3932(98)00135-3

were incongruent in size both reach and grasp components must be selected for action. Results suggest that the presentation of distractors had no effects on the kinematics of the reach-to-grasp movement. No interference effects were observed.

In a similar study, Jackson and his colleagues [15] presented target objects at an equal distance from the subject, to the right and to the left. The location of distractor objects was either to the right or the left of the two potential target positions. The objects were a wooden block and a wooden cylinder. Their findings revealed no interference effects for either the reach, or the grasp component of the prehension movement, under normal viewing conditions.

A possible explanation for the difference between these two latter studies and Tipper et al. [37] findings could be that in the Chieffi et al. [8] and Jackson et al. [15] studies reaching to grasp occurs at natural speed after the initial selection for action process has taken place. This is because the objects are seen by the subjects before the onset of the experimental trial, and thus the distractor information could be disregarded altogether in the selection of the target. In the study by Tipper et al. [37], because the objects are not seen before the onset of each trial and movements are performed at maximum speed, the selection for action process must instead take place after the movement has started.

In an attempt to investigate these target/distractor effects with more ecological kinds of stimuli, Castiello [5] (see also [4]) used a selection of fruit as experimental objects. The stated aim of Castiello's [5] study was to establish basic kinematic data for reach to grasp movements for an apple presented with various other fruits. Results for this study challenge the view that competing information may lead to interference effects in the selection for action process. No significant interference effects were observed for either the reach or the grasp components when fruits were presented in various combinations. This was in spite of the fact that differently shaped fruit, when distractor objects, required notionally different types of grasp to the actual target. These results suggest that irrelevant stimuli, if not of immediate behavioral importance are ignored or their influence on action systems is inhibited.

In summary, it is yet unclear under which conditions interference effects manifest reliably. Overall, four factors appear to be critical: (i) speed appears to be crucial for the observation of interference effects [37]; (ii) features of stimuli such as the position of the distractor relative to the target [15, 16, 37]; (iii) the size of the distractor [4, 5, 22]; (iv) the degree of cognitive processing devoted to the distractor [5, 37].

A point that should be stressed in light of the above mentioned papers, is that the experimental objects within each experiment were all in the same semantic category, geometric shapes and fruits.

The neuropsychological literature has provided evidence of separate neural mechanisms for the recognition of living things and non-living things [24, 35, 40]. Moreover, recent results from brain imaging further support the existence of category-specific neural channels [33, 36]. Of specific interest to the current study are the results reported by Martin et al. [28]. They found a selectively greater activation of the premotor cortex when tools as opposed to animal pictures were presented. Such a result could imply that the visuomotor processing channels for living things differ from those for non-living things, and links with the idea of a semantic system concerned also with the functional characteristics of things [34].

Consequently, a simple question can be posed: 'if the target and distractor were in different semantic categories, would this result in changes to the kinematic parameter of the reach or the grasp components of the prehension movement, or both?' In other words, do the semantic attributes of competing objects affect motor control during the selection for action process?

In theories of motor control the emphasis placed upon the semantic attributes of stimuli has been minimal. Perceptual attributes such as the shape and size of an object have been considered as exerting a major influence on the planning of goal directed movements (for review see [2]). Until the single case study of LP [6] there was little support for investigating the effects of semantic attributes on movement organisation. LP's perceptuomotor deficit consisted in the inability to put together two cards depicting non-living things. If the pictures were of living objects from the same sub-category, LP performed the action in a co-ordinated manner. Hence the ability of LP to perform a bilateral motor action varied according to the semantic attributes of the stimuli. In this connection Bennett et al. [3] applied the same bilateral reach-to-grasp paradigm to healthy participants where movements preceding the action of putting living things and non-living things together were recorded. The use of a bilateral task allowed to investigate whether semantic relation between stimuli would disrupt the classic co-ordinative pattern found for bimanual movements [20]. They found that movements where living-thing pairs had to be put together were faster, and showed earlier settings of reach and grasp temporal parameters than movement involving pairs of non-living things. Together with the case study of LP, the finding of differential activation of motor regions according to category pointed to the relevance for investigating semantic influences on movement selection processes. In the current study three experiments investigated the effect of a distractor object that belonged to a different semantic category than the target object.

2. Experiment 1

The aim of this experiment was to assess whether the kinematic parameters of the reach and the grasp components of prehension differed when a target was presented either alone, with another object of the same semantic category, or an object which was perceptually and semantically different from the target. It was predicted that, when the target and the distractor object were different, changes might be observed to the kinematics of the movement sequence.

2.1. Method

2.1.1. Participants

Eight undergraduate students, (4 women, 4 men, aged between 19 and 30 years, $M = 22.63$ years, SD = 3.5) volunteered to participate. All were right-handed according to the Edinburgh Inventory [31] and reported normal or corrected-to-normal vision. Subjects were naive to the purpose of the experiment. Each participant attended one experimental session of approximately 30 min duration.

2.1.2. Apparatus and materials

The experiment was conducted under normal room lighting. Details of the experimental setup are shown in Fig. 1. The participant was seated in front of the table working surface (1 × 1 m). Before each trial, the subject's hand was positioned 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 red apple (70 mm diameter) was presented so that it was 30 cm from the starting position. The position of the target was central to the midsagittal plane. A second identical apple, (the compatible distractor), or a red cardboard rectangular box, (the incompatible distractor) (70 × 60 × 60 mm), was individually presented 20° to the right, or 20° to the left of the central apple (Fig. 1). In summary, the central target apple was presented alone (no distractor), or in the presence of an apple (compatible distractor), or with a box (incompatible distractor). The order of presentation was randomised. The objects were not visible prior to trial onset. In order to minimise the time of stimuli processing a screen was placed between the participant and the experimental objects during stimulus arrangement.

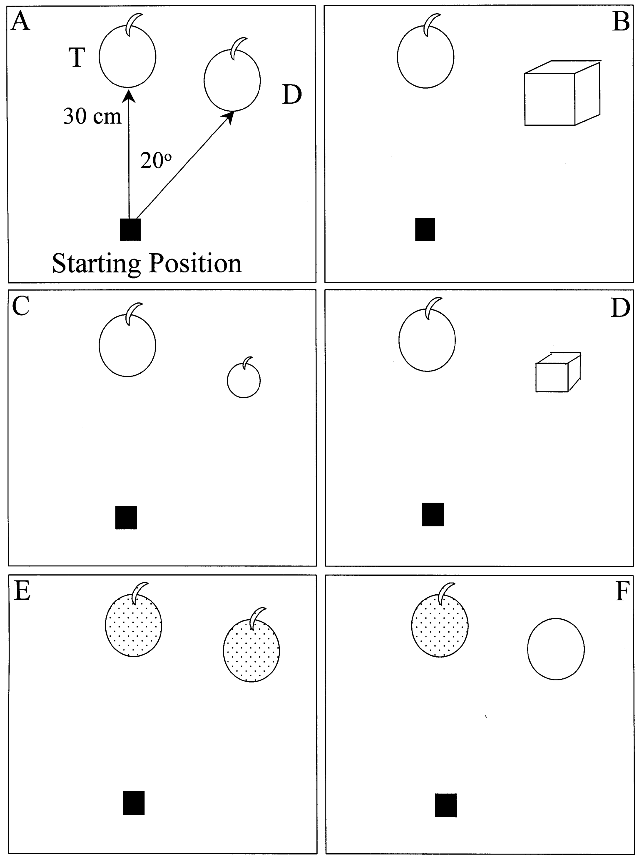

Fig. 1. Experimental set up for Experiment 1 (upper panels), Experiment 2 (middle panels) and Experiment 3 (lower panels). Panel *A* represents the compatible distractor condition for Experiment 1. Panel *B* represents the incompatible distractor condition for Experiment 1. Panel *C* represents the compatible distractor condition for Experiment 2. Panel *D* represents the incompatible distractor condition for Experiment 2. Panel *E* represents the compatible distractor for Experiment 3. Panel *F* represents the incompatible distractor for Experiment 3. T = Target; D = Distractor.

2.1.3. Recording

Reflective passive markers (0.25 cm in diameter) were attached to three points, the first was on the wrist (the radial aspect of the distal styloid process of the radius), the second was on the index finger (the radial side of the nail), and the third was on the thumb (the ulnar side of the nail). Movements were recorded with the ELITE system [11]. 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 surface was parallele-piped (60 cm long × 30 cm wide × 60 cm high) from which the spatial error measured from stationary and moving stimuli was 0.4 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 [13], the mean length of a bar with two markers attached 15 cm apart, as reconstructed from ELITE data, was 14.6 cm (SD = 0.12 cm). Co-ordinates of the markers were reconstructed with an accuracy of 1/3000 over the field of view and sent to a host computer. The standard deviation of the reconstruction error was 1/3000 for the vertical (Y) axis and 1.4/3000 for the two horizontal (*X* and *Z*) axes.

2.1.4. Procedure

Thirty trials were performed altogether; 10 trials for the no distractor condition, 10 trials for the compatible distractor condition, and 10 trials for the incompatible distractor condition. These were presented in random order and counterbalanced for right and left position of the distractor objects.

The screen in front of the experimental objects was raised and a warning tone sounded to signal the participant to start each trial. The participant was required to reach and grasp the centrally located object, and to lift it briefly from its position on the working surface, on every trial. The start of the movement was recorded as the time the participant's hand left the pressure sensitive switch. The end of the movement was recorded as the time the fingers closed on the target. The movement after the target had been grasped was not relevant to the experiment and was not assessed.

There were no instructions about maximising the speed of the movement. It was stressed that a normal movement, similar to that used for reaching and grasping familiar objects, was a requirement for the purposes of the experiment.

2.1.5. Data processing

The Eligrasp (BTS, 1994) software package was used to assess the data. This gave a three-dimensional reconstruction of the marker positions. The data were then filtered using an FIR linear filter with a transition band of 1 Hz (sharpening variable = 2; [9, 10]). Analysis of the acceleration and velocity of the wrist marker allowed assessment of the reaching component. Analysis of the markers on the thumb and index finger allowed assessment of the grasp component. The start of the movement was signaled by the release of the pressure starting switch. The end of the movement was taken as the time when movement of the fingers ceased after they had closed on the object. No further assessment took place after finger closure.

The dependent variables specifically relevant to the scientific hypothesis under test have been analysed. Given previous results of interference an increase in initiation time and movement duration when both the target and the distractor were presented was expected [4, 5, 37, 38]. To investigate whether the temporal occurrence of the reaching component parameters varied when the target was presented with a distractor rather than in isolation the times to peak velocity, peak acceleration and peak deceleration were analysed in relative terms as a percentage of the total movement duration. Changes to the movement may be understood more clearly when the occurrence of kinematic events are expressed in terms relative to the overall movement duration. This is because, for a constant movement duration, kinematic events could occur at different percentages between conditions, or between experiments. For the grasp component, time to maximum peak grip aperture and peak grip velocity, the amplitude of peak grip aperture and peak grip velocity for both the opening and closing phases were analysed. Measurements for the opening and closing phases of the hand movement related to the rate of maximum velocity, and the time at which this occurred were considered. Maximum grip aperture was the greatest distance reached between the thumb and the index finger, and the time of its occurrence. These data were analysed using an analysis of variance (ANOVA) whereby the within subject factor was type of distractor (no distractor, compatible distractor, and incompatible distractor). The means for each kinematic parameter in the three experimental conditions were determined for each group of subjects. Where necessary, significant effects were further analysed using the Neuman—Keuls test for pairwise comparisons. A preliminary analysis was conducted in order to investigate whether the effects for right and left distractor objects were asymmetric. For example, Jackson et al. [15, 16] have shown that for right-handed reaches it is the right-side distractor that produces more interference. No significant effects due to position (right or left) or interaction between position and type of distractor for any of the dependent measures of our interest were found. These analyses were conducted for all three experiments of this study. For this reason data were collapsed over left and right distractor items.

2.2. Results and discussion

Data and statistics for the three experimental conditions, are presented in Table 1. The time to initiate the movement was not affected by the flanker/distractor manipulation. This result suggests that processing time before the start of the action is not affected by the categorical relationship between the target and the distractor object or merely when a distractor is present independently from its semantic attributes. However, the results demonstrate that organisation of the reach to grasp movement varied according to the semantic relationship between target and distractor objects. In particular, several parameters of the grasp component reached significance. It was observed that there was a significant difference between the no distractor condition and the incompatible distractor condition for the velocity and acceleration of finger opening. Examination of the relative values at which the significant kinematic events occurred shows that there was a consistent trend in which these events, in the incompatible distractor condition, occurred significantly earlier than the no distractor condition (Table 1 and Fig. 2). These changes to the kinematic parameters of the grasp component were accommodated within a movement time that did not differ significantly for the three conditions (Table 1). The action of opening and closing the hand during the reaching action showed differences according to the semantic relationship between target and distractor objects [2]. Post-hoc comparisons revealed that in relative terms, for the hand opening phase, time to peak acceleration and velocity (referring to the maximum rate of acceleration

Table 1
Mean values for movement duration (ms), and kinematic variables expressed in absolute terms and as a percentage of movement duration for the different experimental conditions in Experiment 1

	ND (SD)	CD (SD)	ID (SD)	Statistics
Movement duration (ms)	851 (177)	842 (178)	827 (142)	ns
Reach component				
Time to peak acceleration (ms)	297 (32)	295 (32)	265 (28)	ns
(%)	35 (3)	35 (4)	32 (3)	ns
Time to peak velocity (ms)	434 (47)	437 (46)	405 (43)	ns
(%)	51 (6)	52 (4)	49 (4)	ns
Time to peak deceleration (ms)	587 (64)	598 (61)	562 (64)	ns
(%)	69 (7)	71 (8)	68 (6)	ns
Grasp component				
Opening				
Time to peak acceleration (ms)	238 (26)	227 (24)	165 (18)	$F(2,14) = 35.61$ $P < 0.0001$
(%)	28 (3)	27 (3)	20 (2)	$F(2,14) = 45.87$, $P < 0.0001$
Time to peak velocity (ms)	340 (37)	320 (40)	265 (29)	$F(2,14) = 28.31$, $P < 0.0001$
(%)	40 (4)	38 (3)	32 (2)	$F(2,14) = 38.57$, $P < 0.0001$
Time maximum grip aperture (ms)	579 (62)	555 (64)	513 (58)	$F(2,14) = 14.31$, $P < 0.001$
(%)	68 (7)	66 (7)	62 (6)	$F(2,14) = 10.04$, $P < 0.001$
Closing				
Time to peak acceleration (ms)	680 (72)	673 (72)	629 (64)	$F(2,14) = 11.10$, $P < 0.001$
(%)	80 (7)	80 (8)	76 (7)	$F(2,14) = 9.02$, $P < 0.001$
Time to peak velocity (ms)	749 (82)	733 (77)	795 (72)	$F(2,14) = 21.15$, $P < 0.0001$
(%)	88 (8)	87 (9)	84 (8)	$F(2,14) = 10.21$, $P < 0.001$

Note: ND = No Distractor, CD = Compatible Distractor, ID = Incompatible Distractor, ns = not significant.

and velocity at which the thumb and forefinger move apart as the hand opens), occurred earlier in the incompatible condition than the compatible and the no distractor condition (acceleration: 20, 27 and 28%, respectively; velocity: 32, 38 and 40%, respectively; Ps < 0.01). Thus, the finger and thumb began to open, and reached the greatest opening rate earlier when an incompatible distractor was presented compared to no distractor being present. The time of maximum grip aperture occurred earlier in the incompatible condition (62%) compared with 66% in the compatible condition and 68% with the no distractor condition (Ps < 0.05). Differences between the compatible and the no distractor conditions were not significant for each of the dependent measures (Table 1). Figure 2 shows the result for the grasp component parameters expressed as a percentage of movement duration. These early effects may reflect a compensatory strategy that allows the fingers a longer deceleration and positioning time. This statement is supported by the significant greater percentage of movement time spent from the time of maximum grip aperture to the end of movement (closing time) for the incompatible distractor condition than the compatible and the no distractor conditions (38, 34 and 32%; $P < 0.01$). Post-hoc comparisons also revealed that this percentage of movement duration was not different when comparing the compatible with the no distractor condition (33 vs 31%; Fig. 2). Unlike recent findings where the semantic relationship between two stimuli influences both transport and grasp component during a bilateral task [3], in the present study the categorical effect was not found for the reaching component. For example, the rate at which the arm reached its peak acceleration occurred at 35, 35, and 32% of the movement duration in the no distractor condition, the compatible distractor condition and the incompatible condition, respectively. Peak velocity, for the reach component, was reached at 51, 52, and 49% of movement duration in the no distractor, compatible distractor, and incompatible distractor conditions, respectively. Similarly for the no distractor, the compatible distractor, and the incompatible distractor conditions, the arm's peak deceleration occurred at 69, 71, and 68% respectively. The different nature of the task, bilateral vs unilateral may be responsible for the lack of 'semantic' effect between the current and the Bennett et al.[3] experiment. In bilateral movement the interlimb co-ordination may have made the semantic manipulation more sensitive.

In conclusion these results indicate interference to the normal patterning of grasp kinematics. In other words, processing of the visual information from a distractor object of a different semantic category than the target led to a disturbance at the level of the grasp component being anticipated.

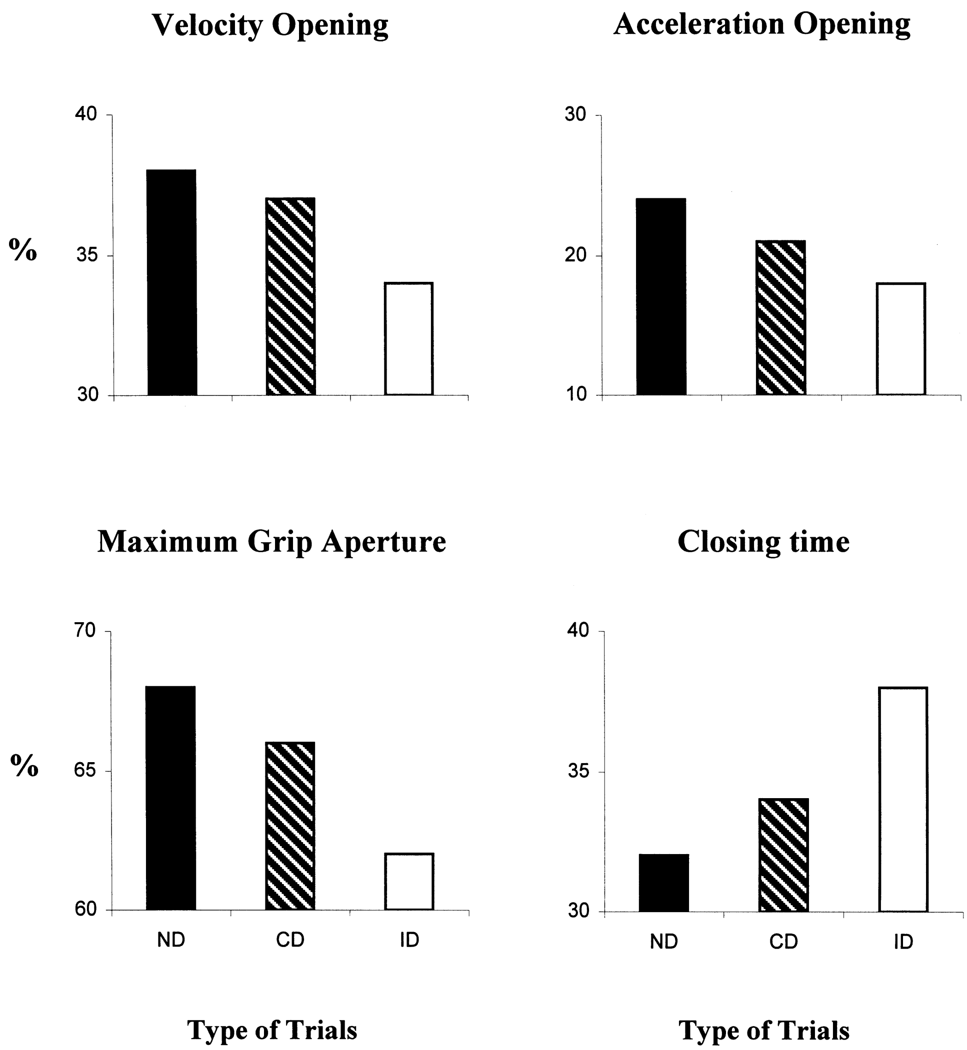

Fig. 2. Temporal parameters for the grasp component expressed as a percentage (%) of movement duration which varies for the three distractor conditions for Experiment 1. ND = No Distractor; CD = Compatible Distractor; ID = Incompatible Distractor.

3. Experiment 2

The aim of this experiment was to observe the effects of changing attributes of the distractor while maintaining the same semantic relationship between target and distractor, and by varying attributes of the distractor whilst maintaining a different semantic relationship between target and distractor. In Experiment 1 the incompatible distractor object had different semantic attributes than the target although its working space (size) was similar to that of the target. In the present experiment a change in distractor size, was considered. The target object (the apple) remained the same as in Experiment 1, but both distractor objects were smaller by approximately 50%. This reduction in size required a different type of grasp for the distractor, a precision grip, compared to the target which required a whole hand grasp.

By manipulating size as well as semantic category, it may be possible to investigate the relationship between semantic attributes and functional properties (type of grasp) of objects. Do target and distractor objects compete on the basis of the possible action they afford? Is this functional aspect separated by the semantic aspect? Are both functional and semantic attributes contained in a single object representation file?

3.1. Method

3.1.1. Participants

Eight undergraduate students (5 women, 3 men, aged between 18 and 33 years, $M = 21.13$ years, $SD = 4.86$) volunteered to participate. These subjects had the same characteristics as those in Experiment 1. Each participant attended one experimental session of approximately 30 min duration.

3.1.2. Apparatus and material

The only changes in this experiment were to the distractor objects. The target object remained the same, a plastic normal sized red apple (70 mm diameter), but the compatible distractor used here was a miniature red apple (30 mm diameter) and the incompatible distractor, a red box ($30 \times 30 \times 30$ mm), scaled to match the smaller apple. In all other respects the apparatus, materials, procedure and data processing were identical to Experiment 1.

3.2. Results and discussion

Data and statistics for Experiment 2 are presented in Table 2.

The data were analysed as for Experiment 1. In this experiment the compatible condition refers to the same semantic category for target and distractor, but the distractor is smaller. The incompatible condition refers to different semantic category, but the distractor is smaller. In contrast to the findings of Experiment 1 movement duration was significantly longer in the incompatible than in the no distractor condition (816 vs 757 ms). Post-hoc comparisons revealed no significant differences between the compatible and the incompatible conditions.

A consistent result within the prehension literature is the longer movement duration for smaller stimuli than for large stimuli [5, 12, 27]. The current result of a longer movement duration suggests that the processing of the smaller distractor influenced kinematics parameterisation for the large object [4, 5]. However, the fact that no differences were found between the compatible and the incompatible distractor conditions suggests that the 'size' effect was overridden or masked by the 'semantic category' effect. Indeed, size was also different in the case of the compatible distractor.

In replication of the first experiment, the same kinematic parameters for the grasp component were significantly different for the incompatible distractor condition when compared with the compatible and the no distractor conditions. Post-hoc comparisons revealed that in relative terms, for the hand opening phase, time to peak acceleration and velocity (referring to the maximum rate of acceleration and velocity at which the thumb and forefinger move apart as the hand opens), occurred earlier in the incompatible condition than the compatible and the no distractor condition (acceleration: 18, 21 and 24%, respectively; velocity: 34, 37 and 38%, respectively; $Ps < 0.01$). Differences between the compatible and the no distractor conditions were not significant (Table 2). For the hand's closing phase, a similar pattern was found. Post-hoc comparisons revealed that in relative terms, for the hand closing phase, time to peak acceleration and velocity occurred earlier in the incompatible condition than the compatible and the no distractor conditions (acceleration: 77, 79 and 80%, respectively; velocity: 85, 87 and 88%, respectively; $Ps < 0.05$). Differences between the compatible and the no distractor conditions

Table 2
Mean values for movement duration (ms), and kinematic variables expressed in absolute and as a percentage of movement duration for the different experimental conditions in Experiment 2

	ND (SD)	CD (SD)	ID (SD)	Statistics
Movement duration (ms)	757 (84)	793 (129)	816 (85)	$F(2,14) = 10.6$, $P < 0.001$
Reach component				
Time to peak acceleration (ms)	242 (26)	270 (29)	269 (25)	ns
(%)	32 (3)	34 (4)	33 (4)	ns
Time to peak velocity (ms)	371 (42)	404 (43)	408 (45)	ns
(%)	49 (5)	51 (5)	50 (5)	ns
Time to peak deceleration (ms)	530 (55)	547 (62)	554 (62)	ns
(%)	70 (7)	69 (6)	68 (6)	ns
Grasp component				
Opening				
Time to peak acceleration (ms)	182 (21)	166 (16)	147 (16)	$F(2,14) = 9.18$, $P < 0.001$
(%)	24 (2)	21 (2)	18 (2)	$F(2,14) = 34.7$, $P < .0001$
Time to peak velocity (ms)	288 (32)	293 (32)	277 (29)	$F(2,14) = 7.02$, $P < 0.05$
(%)	38 (3)	37 (3)	34 (3)	$F(2,14) = 22.0$ $P < 0.0001$
Time maximum grip aperture (ms)	515 (62)	523 (59)	505 (57)	$F(2,14) = 5.06$, $P < 0.05$
(%)	68 (7)	66 (7)	62 (6)	$F(2,14) = 43.3$, $P < 0.0001$
Closing				
Time to peak acceleration (ms)	606 (63)	626 (71)	628 (72)	ns
(%)	80 (8)	79 (8)	77 (7)	$F(2,14) = 10.0$, $P < 0.001$
Time to peak velocity (ms)	666 (81)	689 (77)	693 (75)	ns
(%)	88 (8)	87 (7)	85 (8)	$F(2,14) = 9.06$, $P < 0.001$

Note: ND = No Distractor, CD = Compatible Distractor, ID = Incompatible Distractor, ns = not significant.

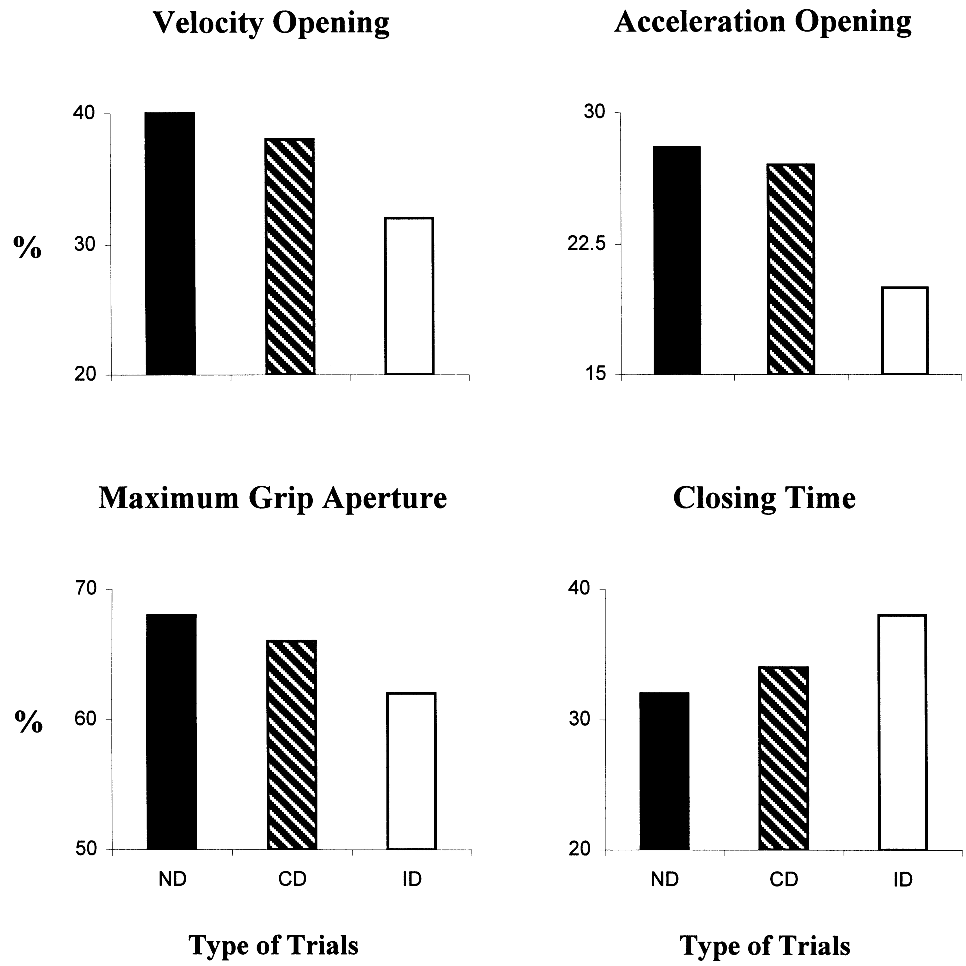

Fig. 3. Temporal parameters for the grasp component expressed as a percentage (%) of movement duration which varies for the three distractor conditions for Experiment 2. ND = No Distractor; CD = Compatible Distractor; ID = Incompatible Distractor.

were not significant (Table 2). Similar anticipation was found for the time of maximum grip aperture. Finally, closing time expressed as a percentage of movement duration was significantly longer for the incompatible than the compatible and the no distractor conditions (38, 34 and 32%, respectively; $P < 0.01$). Differences between the compatible and the no distractor conditions were not significant (Fig. 3).

4. Experiment 3

The primary findings for Experiments 1 and 2 were that while the compatible (apple) distractor produced minimal interference effects, the incompatible (box) distractor produced significant changes in movement kinematics. It was suggested that these results are a consequence of the semantic category of each object (i.e. living vs non-living). However it could be argued that an alternative possible explanation is that the two objects differ in shape. An object that is approximately spherical affords a quite different reach-to-grasp movement than a cube. A cube is usually grasped on one or other pairs of opposing faces. A spherical object imposes lesser constraints on how it should be grasped [32].The present experiment controls for the condition in which the target and the distractor belong to a different semantic category but are similar in shape.

4.1. Method

4.1.1. Participants

Eight undergraduate students (8 women, aged between 18 and 31 years, $M = 21.75$ years, $SD = 5.15$) volunteered to participate. These subjects had the same characteristics as those in Experiments 1 and 2. Each participant attended one experimental session of approximately 30 min duration.

4.1.2. Apparatus and material

The target and the compatible distractor objects were, a plastic normal sized orange (70 mm diameter), but the incompatible distractor used here was an orange plastic sphere (70 mm diameter). In all other respects the apparatus, materials, procedure and data processing were identical to the previous experiments.

4.2. Results and discussion

In replication of the previous experiments, the same kinematic parameters for the grasp component were significantly different for the living distractor condition when compared with the non-living and the no distractor conditions. Post-hoc comparisons revealed that in relative terms, for the hand opening phase, time to peak acceleration and velocity, occurred earlier in the sphere than in the fruit condition than the no distractor condition (acceleration: 15, 18 and 19%, respectively; velocity: 25, 26 and 28%, respectively; $P\mathrm{s} < 0.01$). Differences between the fruit and the no distractor conditions were not significant (Table 3). For the hand's closing phase, a similar pattern was found. Post-hoc comparisons revealed that in relative terms, for the hand closing phase, time to peak acceleration and velocity occurred earlier in the sphere incompatible condition than the fruit compatible and the no distractor condition (acceleration: 29, 32 and 34%, respectively; velocity: 68, 72 and 78%, respectively; $P\mathrm{s} < 0.05$). Finally, closing time expressed as a percentage of movement duration was significantly longer for the sphere than the fruit and the no distractor conditions (28, 29 and 31%, respectively; $P < 0.05$). Differences between the compatible and the no distractor conditions were not significant (Fig. 4).

In conclusion these results further indicate that the perceptual processing which mediates normal reach-to-grasp actions makes use of semantic information.

5. General discussion

The experiments reported in this article sought to investigate what effect the presence of a semantically incompatible distractor would have on the kinematic parameters of the reach to grasp movement toward the target. It was predicted that when the distractor and the target were different, the kinematics would be affected because of the conflict between the semantic attributes of the distractor and the target.

The results from Experiment 1 did not totally support this prediction. The kinematics of the grasp component, but not that of the reach component, did change through the different experimental conditions. The same pattern was found for Experiment 2. However, in this latter experiment movement duration was found to be significantly different between the different experimental conditions.

The main differences between the present and former

Table 3
Mean values for movement duration (ms), and kinematic variables expressed in absolute terms and as a percentage of movement duration for the different experimental conditions in Experiment 3

	ND (SD)	CD (SD)	ID (SD)	Statistics
Movement duration (ms)	731 (139)	735 (139)	749 (148)	ns
Reach component				
Time to peak acceleration (ms)	206 (58)	204 (73)	204 (73)	ns
(%)	28 (4)	28 (8)	27 (6)	ns
Time to peak velocity (ms)	346 (58)	337 (60)	353 (76)	ns
(%)	47 (4)	46 (5)	47 (4)	ns
Time to peak deceleration (ms)	450 (73)	438 (79)	457 (81)	ns
(%)	62 (6)	60 (8)	61 (5)	ns
Grasp component				
Opening				
Time to peak acceleration (ms)	140 (41)	131 (43)	115 (30)	$F(2,14) = 7.43$, $P < 0.05$
(%)	19 (6)	15 (6)	18 (4)	$F(2,14) = 11.43$, $P < 0.001$
Time to peak velocity (ms)	205 (42)	190 (52)	186 (56)	$F(2,14) = 5.42$, $P < 0.05$
(%)	28 (6)	26 (6)	25 (4)	$F(2,14) = 10.03$, $P < 0.05$
Time maximum grip aperture (ms)	526 (94)	520 (84)	512 (84)	$F(2,14) = 5.32$, $P < 0.05$
(%)	71 (5)	68 (5)	68 (7)	$F(2,14) = 5.21$, $P < 0.05$
Closing				
Time to peak acceleration (ms)	245 (111)	239 (95)	212 (95)	$F(2,14) = 10.86$, $P < 0.001$
(%)	34 (15)	32 (12)	29 (11)	$F(2,14) = 21.04$, $P < 0.0001$
Time to peak velocity (ms)	569 (149)	529 (139)	509 (154)	$F(2,14) = 35.54$, $P < 0.0001$
(%)	78 (9)	72 (7)	68 (8)	$F(2,14) = 27.32$, $P < 0.0001$

Note: ND = No Distractor, FD = Fruit Distractor, SD = Sphere Distractor, ns = not significant.

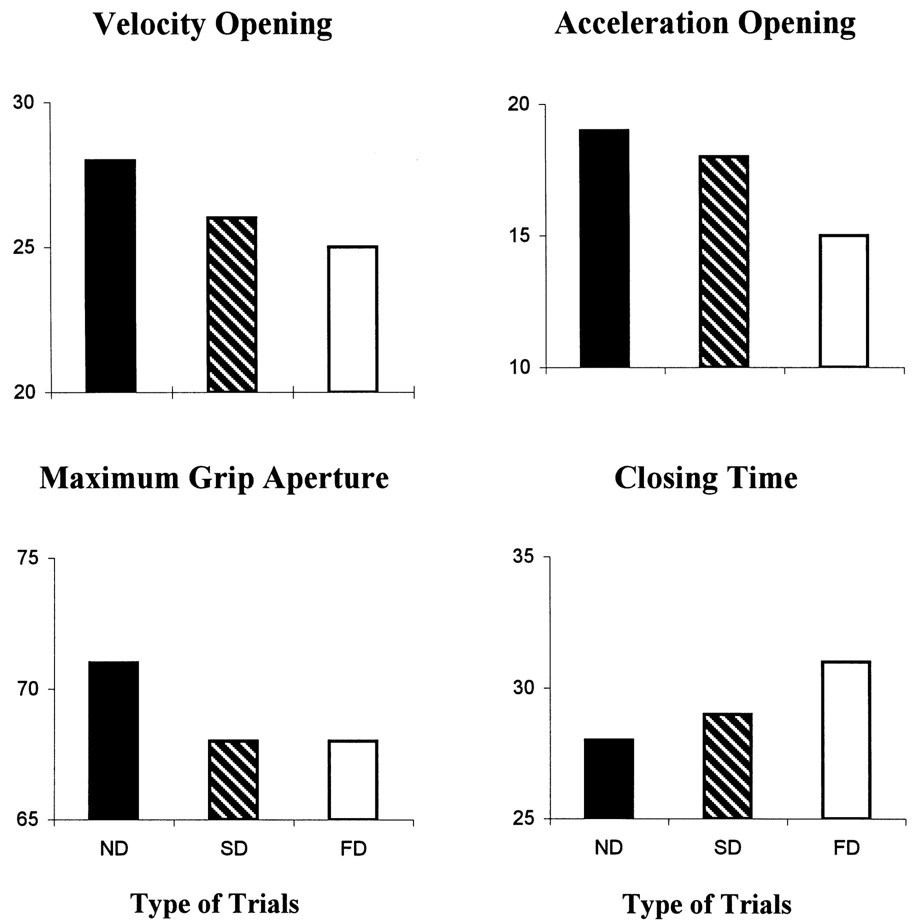

Fig. 4. Temporal parameters for the grasp component expressed as a percentage (%) of movement duration which varies for the three distractor conditions for Experiment 3. ND = No Distractor; FD = Fruit Distractor; SD = Sphere Distractor.

studies [4, 5, 8, 15, 37] is that the objects belong to the same semantic categories. The finding that the reach-to-grasp action was affected as a consequence of a semantic conflict between target and distractor indicates that processing of different objects in the visual field is subjected to the attributional relationship between these objects. As suggested by Mandler [26] we may have conceptual primitives of objects in our environment which influence planning. Of interest is to understand which are the neural networks that determine the functional linkage between primitives and planning for action.

Using a well-known terminology these neural networks may be part of the perceptuomotor pathways. A certain degree of caution is necessary for claiming that the differences found between the living thing (fruit) and non-living thing (box) used in the present study demonstrate different perceptuomotor pathways for different semantic categories. However, the 'interference' effects reported in the present article might be the result of simultaneous activation of different 'semantic' neural structures relevant for motor output formation [28]. In other words, the semantic properties of the distractor are encoded and evoke parallel computation with the semantic properties of the target. As suggested by Tipper et al. [37] if two objects are presented, the target and the distractor, the information coming from the distractor needs to be inhibited, yet it is this inhibition that causes interference.

In the current experiments, it could be questioned that not only the attributes manipulated were semantic, but also perceptual. The perceptual features of the incompatible distractor object may have contributed in determining interference effects. The presence of this incompatible distractor object, a box, led to some of the kinematic parameters of the grasp component occurring earlier than when no distractor was presented. As the hand opened, it reached its peak of acceleration and velocity earlier, which resulted in an anticipated maximum aperture being reached earlier in the incompatible condition than the no distractor condition. When the target is curved and the distractor has straight features a conflict for the parallel processing of these incongruent features may determine changes in the grasp component.

Naturally a round object requires a grasp that differs from a cube shaped object. Fingers have to be positioned in a slightly different way. Thus the parallel to-be-ignored action evoked by the distractor dictated by the different perceptual features may have determined the interference effects reported in the present article. However, whether it is the perceptual attributes and not the semantic category of the distractor that determine differences is an issue that can be debated [23]. Although only limited research has been conducted on the details of processing of curvature, Treisman and Gormican [39] suggested that curvature maybe a reasonable candidate to be a basic feature. They suggest, however, that curved lines which could be found in parallel among straight distractors do not induce interference type effects. If this is the case it is likely that the changes found in the grasp component are not due to a mismatch between perceptual features but to motor functional semantic aspects contained in the files where object representations are stored. However, the 'semantic' argument is further supported from the results obtained for Experiment 2 and 3 where size and shape were manipulated, respectively. Although kinematic parameters for the grasp component were seen to show the same trend observed in Experiment 1, the opening and closing phases of the grasping action were affected only when the distractor was different both for size and semantic category. For Experiment 2 when the distractor was different in size but similar from a semantic category point of view, no changes were noticed. For Experiment 3 when the shape of the distractor was similar to the shape of the target but target and distractor belong to different semantic categories interference were noticed. Thus it seems that semantic incongruence between the target and the distractor are responsible for such interference effects. In other words, response selection is dependent upon semantic categorisation processes. Stimuli which appear to be fully processed by the perceptual system may or may not affect response selection processes, depending on whether they are associated with responses on the basis of the dimension of the target [7].

One of the experimental questions of the present paper was whether target and distractor objects compete on the basis of the possible action they afford and whether this functional aspect is separated by the semantic aspect. A possible answer is that both functional and semantic attributes are contained in a single object representation system and linked to each other. In the second experiment of the present study, an apple requiring a whole hand prehension was presented with a small box requiring a more precise grasp as a distractor. This was the critical condition which produced changes in the kinematics of the reach-to-grasp movement to a target. In line with Castiello [5] propositions, the presentation of competing grasp information from more than one object in the visual field evokes a parallel action program which determines interference effects. In other words, distractors automatically activate their responses without the subjects intention to act [25]. Thus, different objects in a visual scene may evoke the parallel implementation of actions [37]. If more than one motor pattern is kept active at a time this parallel activation may determine mutual interference. The question now is, are action programs dictated specifically by the size of the object or by other basic perceptual features? From the results obtained for the condition where the objects belong to the same semantic category, but differ in size (Experiment 2: compatible condition) it is evident that the 'only size' hypothesis cannot be the case, otherwise changes as those found for the incompatible condition should have been noticed.

Klatzky et al. [21] 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 cognitive and functional properties of objects. In light of this body of data it is suggested that conflicts emerge when the distractor and target objects are semantically different and require different prehensile pattern, in order to be grasped or manipulated. Semantic and functional properties for the irrelevant distractor object are alerted and interfere with semantic and functional properties activated and executed for the target object. Consequently, it could be speculated that how to grasp and manipulate an jyobject is part of an object representation system which links semantic and functional knowledge about the object.

As a final point a few remarks should be made regarding the differences in the results obtained in the present study and those of previous 'distractor' experiments [5, 8, 15]. In the present experiment, time of exposure before movement initiation was limited. Tipper et al. [37] for example, have shown this to be an important factor that can determine interference. In comparison, for conditions in which experimental objects have been presented before movement onset, an appropriate motor output could be selected for the target and consequently competing information from the distractor objects could be effectively discounted [5, 8, 15]. For the present study, the interference effects could be explained by claiming that the distractor information remained salient, until it had been processed sufficiently to be suppressed. As a reflection of the filtering process for to-be-ignored information, the appropriate selection for action toward the target was affected. Nevertheless, the finding that when the compatible distractor was present no interference effects were found suggests that such effects are related to the intrinsic nature of the relationship between target and distractor.

In conclusion, the results of the present study support the notion of an 'implicit categorical motor processing' level. It would seem that in the event of objects belonging to a different semantic category being presented as target and distractors, there are effects on the kinematics of the reach-to-grasp movement to the target.

Acknowledgements

This study was supported by an Australian Research Council Grant to UC and KB. We would like to thank Dr Ada Kritikos for her comments on the previous version of this manuscript. Ms Rachael Sanders is also thanked for helping with data acquisition and data analysis.

References

[1] Allport A. Selection for action: Some behavioral and neurophysiological considerations of attention and action In: Heuer H, Sanders AF, editors. Perspectives on perception and action. Hillsdale, NJ: Erlbaum, 1987. p. 395–419.
[2] Bennett KMB, Castiello U. Insights into the reach to grasp movement. Amsterdam: North Holland, 1994.
[3] Bennett KMB, Thomas JI, Jervis C, Castiello U. Upper limb movement differentiation according to taxonomic semantic category. NeuroReport 1998;9:255–62.
[4] Bonfiglioli C, Castiello U. Selective interference effects during prehension movements. Perception & Psychophysics.
[5] Castiello U. Grasping a fruit: Selection for action. Journal of Experimental Psychology: Human Perception and Performance 1996;22:582–603.
[6] Castiello U, Scarpa M, Bennett K. A brain-damaged patient with an unusual perceptuomotor deficit. Nature 1995;374:805–8.
[7] Cohen A, Shoup R. Perceptual dimensional constraints in response selection processes, Cognitive Psychology 1997;32:128–81.
[8] Chieffi S, Gentilucci M, Allport A, Sasso E, Rizzolatti G. Study of selective reaching and grasping in a patient with unilateral parietal lesion. Brain 1993;116:1119–37.
[9] D'Amico M, Ferrigno G. Technique for the evaluation of derivatives from noisy biomechanical displacement data using a mode-based bandwidth-selection procedure. IEEE, Transaction Biomedical Engineering 1990;28:407–15.
[10] D'Amico M, Ferrigno G. Comparison between the more recent techniques for smoothing and derivative assessment in biomechanics. IEEE, Transaction Biomedical Engineering 1992;30:193–204.
[11] Ferrigno G, Pedotti A. ELITE: A digital dedicated hardware system for movement analysis via real-time TV signal processing. IEEE, Transaction Biomedical Engineering 1984;32:943–50.
[12] Gentilucci M, Castiello U, Corradini ML, Scarpa M, Umiltà C, Rizzolatti G. Influence of different types of grasping on the transport component of prehension movements. Neuropsychologia 1991;29:361–78.
[13] Haggard P, Wing A. Assessing and reporting the accuracy of position measurements made with optical tracking systems. Journal of Motor Behaviour 1990;22:315–21.
[14] Howard LA, Tipper SP. Hand deviations away from visual cues: indirect evidence for inhibition. Experimental Brain Research 1997;113:144–52.
[15] Jackson SR, Jackson GM, Rosicky J. Are non-relevant objects represented in working memory? the effects of non-target objects on reach to grasp kinematics. Experimental Brain Research 1995;102:519–30.
[16] Jackson SR, Jones CA, Newport R, Pritchard C. A kinematic analysis of goal-directed prehension movements executed under binocular, monocular, and memory-guided viewing conditions. Visual Cognition 1997;4:113–42.
[17] Jeannerod M. In: Long J, Baddeley A, editors. Attention and performance IX. Hillsdale, NJ: Erlbaum, 1981. p. 153–68.
[18] Jeannerod M. The timing of natural prehension movements. Journal of Motor Behaviour 1984;16:235–54.
[19] Jeannerod M. In: Bennett KMB, Castiello U, editors. Insights into the reach to grasp movement. Amsterdam: North-Holland, 1994. p. 151–70.
[20] Kelso JAS, Southard DL, Goodman D. On the co-ordination of 2-handed movements. Journal of Experimental Psychology: Human Perception and Performance 1979;5:229–38.
[21] Klatzky RL, McCloskey B, Doherty S, Pellegrino J, Smith T. Knowledge about hand shaping and knowledge about objects. Journal of Motor Behavior 1987;19:187–213.
[22] Kritikos A, Bennett KMB, Dunai J, Castiello U. Interference from distractors in reach-to-grasp movements. Quarterly Journal of Experimental Psychology (in press).
[23] Kritikos A, Bennett KMB, Dunai J, Castiello U. Distractor interference: Semantic category or visual form? Manuscript submitted for publication.
[24] Laicona M, Barbarotto R, Capitani E. Perceptual and associative knowledge in category specific impairment of semantic memory: A study of 2 cases. Cortex 1993;29:727–40.
[25] Lhermitte F. 'Utilization behavior', and its relation to lesions of the frontal lobes. Brain 1983;106:237–55.
[26] Mandler JM. How to build a baby: conceptual primitives. Psychological Review 1992;99:587–604.
[27] Marteniuk RG, Leavitt JL, MacKenzie CL, Athenes S. Functional relationships between the grasp and transport components in a prehension task. Human Movement Science 1990;9:149–76.
[28] Martin A, Wiggs CL, Ungerleider LG, Haxby JV. Neural correlates of category specific knowledge. Nature 1996;379:649–52.
[29] Napier JR. The prehensile movements of the human hand. Bone Joint Surgery 1956;38:902–13.
[30] Neuman O. In: Heuer H, Sanders AF, editors. Perspectives on perception and action. Hillsdale, NJ: Erlbaum, 1987. p. 395–419.
[31] Oldfield RC. The assessment and analysis of handedness: the Edinburgh Inventory. Neuropsychologia 1971;9:97–113.
[32] Paulignan Y, Frak VG, Toni I, Jeannerod M. Influence of object position and size on human prehension movements. Experimental Brain Research 1997;116:226–34.
[33] Perani D, Cappa SF, Bettinardi V, Bressi S, Gorno-Tempini M, Matarrese M, Fazio F. NeuroReport 1995;6:1637–41.
[34] Riddoch MJ, Humphreys GW, Coltheart M, Funnell E. Semantic systems or system? Neuropsychological evidence re-examined. Cognitive Neuropsychology 1988;5:3–27.
[35] Sacchett C, Humphreys GW. Calling a squirrel a squirrel but a canoe a wigwam: a category-specific deficit for object and body parts. Cognitive Neuropsychology 1992;9:73–86.
[36] Spitzer M, Kwong KK, Kennedy W, Rose BR, Belliveau JW. Category-specific brain activation in fMRI during picture naming. NeuroReport 1995;6:2109–12.
[37] Tipper SP, Howard LA, Jackson SR. Selective reaching to grasp: Evidence for distractor interference effects. Visual Cognition 1997;4:1–38.
[38] Tipper SP, Lortie C, Baylis GC. Selective reaching: Evidence for action centred attention. Journal of Experimental Psychology: Human Perception and Performance 1992;18:891–905.
[39] Treisman A, Gormican S. Feature analysis in early vision: evidence from search asymmetries. Psychological Review 1988;95:15–48.
[40] Warrington EK, Shallice T. (1984). Category specific semantic impairments. Brain 1984;107:829–54.
[41] Weir PL. In: Bennett KMB, Castiello U, editors. Insights into the reach to grasp movement. Amsterdam: North-Holland, 1994. p. 129–50.