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RESEARCH ARTICLE

The bottle and the glass say to me: “Pour!”

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Abstract The present study aimed at determining whether the observation of two functionally compatible artefacts, that is which potentially concur in achieving a specific function, automatically activates a motor programme of interaction between the two objects. To this purpose, an interference paradigm was used during which an artefact (a bottle filled with orange juice), target of a reaching-grasping and lifting sequence, was presented alone or with a non-target object (distractor) of the same or different semantic category and functionally compatible or not. In experiment 1, the bottle was presented alone or with an artefact (a sphere), or a natural (an apple) distractor. In experiment 2, the bottle was presented with either the apple or a glass (an artefact) filled with orange juice, whereas in experiment 3, either an empty or a filled glass was presented. In the control experiment 4, we compared the kinematics of reaching-grasping and pouring with those of reaching-grasping and lifting. The kinematics of reach, grasp and lift was affected by distractor presentation. However, no difference was observed between two distractors that belonged to different semantic categories. In contrast, the presence of the empty rather filled glass affected the kinematics of the actual grasp. This suggests that an actually functional compatibility between target (the bottle) and distractor (the empty glass) was necessary to activate automatically a programme of interaction (i.e. pouring) between the two artefacts. This programme affected the programme actually executed (i.e. lifting). The results of the present study indicate that, in addition to affordances related to intrinsic object properties, “working affordances” related to a specific use of an artefact with another object can be activated on the basis of functional compatibility.

Keywords Affordance · Interference · Human kinematics · Semantic category · Artefact

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Introduction

Grasping an object requires the selection of a particular type of grasp. In addition, when the hand approaches the target (i.e. during reaching), the fingers are shaped and, then, closed on the object. Kinematic studies (Chieffi and Gentilucci 1993; Gentilucci et al. 1991, 1994; Jeannerod 1988; Milner and Goodale 1995) have shown that intrinsic object properties, such as size and shape, influence both the selection of the type of grasp and the grasp kinematics, whereas extrinsic properties, such as position, influence the reach kinematics. All these properties elicit affordances of the object. According to Gibson (1979), affordances are possibilities for action provided by means of vision. The idea of affordances would include, in the representation of an object, a description of its visual properties and the motor pattern required to interact with that object (see Jeannerod 1994; Ellis and Tucker 2000; see also Ellis et al. 2007). In this sense, affordances are also motor representations of interactions between effector and object (Barbieri et al. 2007; Gangitano et al. 1998; Gentilucci 2002, 2003). In kinematic studies of arm movements like reaching and grasping, the affordances were studied using interference paradigms, in which the target was presented alone or with a distractor (i.e. an object irrelevant to the motor task). Usually, the intrinsic properties of the distractor were different from those of the target (Castiello et al. 1996; Gangitano et al. 1998). It was observed that the different grasp motor patterns automatically activated by the vision of the distractor (i.e. the distractor affordance) influenced the actual grasp directed to the target. Tipper and colleagues (Tipper et al. 1991, 1997; Howard and Tipper 1997) observed that when individuals reached for a target, their hand movements veered away from distractors even if they were not physical obstacles to the action. Similar effects were also found in tasks requiring saccadic eye movements. When a cue was presented on the right or on the left of fixation, the next saccades deviated away from the locus of the cue (Sheliga et al. 1994, 1995). As Tipper et al. (1991), Sheliga et al. (1994, 1995) interpreted these path deviations as possible reflections of inhibition related to the to-be-ignored cue stimulus. In other experiments (Tresilian 1998; Mon-Williams and McIntosh 2000; Mon-Williams et al. 2001), the presence of a distractor slowed down the movement approaching the target and induced a decrease in maximal finger aperture of grasp. Mon-Williams et al. (2001) and Tresilian (1998) interpreted these results as consequent to the strategy for decreasing the possibility of the fingers colliding with non-target objects in the workspace. Alternatively, these results could be due to interference of the programme directed to the distractor not yet inhibited during movement execution.

Many cognitive models assumed that semantic memory is organized in categories (Capitani et al. 2003). In particular, two main semantic categories have been identified: the category of natural or biological objects (such as animals, fruits and vegetables) and the category of artefacts or man-made objects (such as tools) (Atran 1989; Farah et al. 1996; Warrington and McCarthy 1987). Natural things can be defined in terms of their sensory or perceptual properties. In contrast, artefacts tend to be defined in terms of their functional attributes (i.e. what they are used for) (Sensory Functional Theory; Warrington and Shallice 1984). Consequently, when used as distractors, natural things would interfere with the actual action towards the target on the basis of motor programmes (i.e. affordances) usually related to their physical properties, whereas artefacts would also compete on the basis of their motor programmes defined by functional motor properties (Farah and McClelland 1991). Affordances of artefacts can be, therefore, expressed in terms of motor programmes describing the functions of the object (beside programmes of interactions such as the grasp on the basis of extrinsic and intrinsic tool properties, Borghi et al. 2007; Costantini et al. 2011). Thereby, it is possible to suppose that, when two artefacts (target and distractor) are both presented on a scene, the distractor could activate a motor programme "per se", that is, a structural affordance determined by current information on physical properties of the only distractor and/or a motor programme arising from the combined use of the target with the distractor, that is, a functional affordance based on stored knowledge of object use (Bub et al. 2003, 2008; Creem-Regehr et al. 2007; Jax and Buxbaum 2010). According to Riddoch and Humphreys' group (Riddoch et al. 2003; Yoon et al. 2010), the functional affordances are involved in detecting objects presented within pairs. We hypothesized that the presentation of two artefacts normally associated with the same action (e.g. a full bottle, the target, and an empty glass to be filled, the distractor) can activate a specific programme (i.e. of pouring), which interferes with the action on the target, even if the task does not require the use of the target with the distractor (e.g. reaching, grasping and lifting the bottle).

In experiment 1, participants reached, grasped a bottle (an artefact) and lifted it. The target object was presented alone or with non-target objects. These were a sphere or an apple of the same sizes. The apple belongs to the natural category (Atran 1989; Farah et al. 1996, 1991; Warrington and McCarthy 1987), that is, a category different from that of bottle. In contrast, the sphere was of the same category as the bottle because it was an artefact, but functionally unrelated with it. In sum, the presence of the sphere such as the apple unlikely activates a programme of interaction with the bottle. Consequently, concerning the functional relations with the bottle, we expected no difference in the interference between sphere and apple. It may be noted that the natural object (the apple) placed on a table was not presented in a natural background (i.e. the tree) even if it was on a usual background (i.e. the table). Conversely, the sphere was a wood graspable object that could be used as a bowl. However, its presentation with a bottle in a table plane is less frequent than presentation of apple with bottle. That is, what are called thematic spatial relationships were weaker. Consequently, concerning the thematic spatial relations with the bottle, we might expect less interference effect than the apple. Note that thematic relations correspond to an organization of knowledge in terms of familiar scenes or events and they affect the way categories are formed and used. More specifically, a thematic relation is any temporal, spatial, causal or functional relation between things (Estes et al. 2011), and they can arise from either affordances or convention (Golonka and Estes 2009; Lin and Murphy 2001). A typical relation is spatial (e.g. a roof on top of a house), but thematic relations could be also temporal (e.g. summer and holiday), causal (e.g. wind and erosion), and functional (e.g. fork and knife).

In experiment 2, the interference effect of the apple with that of a filled glass was compared. The glass is semantically compatible with the bottle because it is an artefact and it is also associated with one dominant function (it is used to drink if it is filled with the liquid of the bottle, see Jax and Buxbaum 2010). Nevertheless, actually the full glass was not functionally compatible with the bottle since it was already filled with liquid. Consequently, we expected no difference between the presentation of the apple and the filled glass. In experiment 3, we compared the effect of the filled glass with that of an empty glass. We expected an effect of the empty glass; indeed, actually, the empty glass was functionally compatible with the bottle. In other words, its presentation could automatically activate a programme of pouring the liquid of the bottle into the glass modifying the actual motor programme. Indeed, a previous study (Ansuini et al. 2008) showed that the kinematics of grasp differed when reaching to grasp in order to lift as compared to pour. In other words, the final action and/or its aim can affect the kinematics of an entire sequence of actions (see also Gentilucci et al. 1997; Marteniuk et al. 1987). Finally, experiment 4 was a control aiming at confirming the kinematic differences between motor sequences finalized to pour and to lift.

Experiment 1

In experiment 1, we examined whether in a task requiring reaching, grasping and lifting a bottle (an artefact object), the presence of a distractor of the same semantic category could affect the sequence in a different way with respect to a distractor of a different semantic category. We presented the target alone, or in the presence of a distractor of the same category (a sphere, artefact) or in the presence of a distractor of a different category (an apple, natural object).

Methods

Participants

Eight naïve volunteers (5 women and 3 men, age 22–30 years.) took part in the experiment. All participants were right-handed (Oldfield 1971) and without any history of neurological disorder or impairment. They were paid for their participation. The Ethics Committee of the Medical Faculty at the University of Parma approved the study. The experiments were conducted according to the principles expressed in the Declaration of Helsinki.

Apparatus and stimuli

The participants sat comfortably in front of a table on which they placed their right hand with the thumb and index finger in pinch position (Starting Position, SP). SP was along the participants' mid-sagittal plane and was 27 cm distant from their chest. A bottle filled with orange juice ($\sim$22 cm height, $\sim$5 cm diameter; Fig. 1) was presented to the participants. It was positioned on the table along the participants' mid-sagittal plane, 19 cm distant from SP. The bottle was presented alone or, depending upon the task condition, in the presence of another object on the left, 15 cm distant from the bottle. The distance of this object from the participants' horizontal plane was the same as that of the bottle (Fig. 1). The object could be a yellow apple or a graspable wood sphere or another identical bottle filled with orange juice. The apple and the sphere were approximately of the same size (apple: $\sim$7 cm width, $\sim$8 cm height; sphere: $\sim$8 cm diameter; Fig. 1).

Procedure

The participants performed a go–no-go task. They were required to reach for, pick up and lift the bottle in the presence of the apple or the sphere (distractor condition) or in the absence of any object (no-distractor condition). Each trial started with the participant's eyes closed. When the experimenter gave the "GO" signal, the participant opened his/her eyes, looked at the presented stimuli and then reached, grasped and lifted the bottle (go condition). No instruction was given about the height of the lifting movement. The participants grasped the bottle with their whole right hand (whole hand grasp, Fig. 1). When the second bottle was presented on the table, the participants had to stay still and to wait for the next trial (no-go condition). Before the experiment onset, the participants performed a training block of ten trials. The task was executed in a single block of 40 trials (10 trials/condition) and the order of stimulus presentation was semi-randomized. During the task, the participants were free to look at the scene as during natural interactions with objects and they were asked to perform the movement as naturally as possible.

Data recording

The movements of the participants' right arm were recorded using the 3D-optoelectronic SMART system (BTS Bioengineering, Milano, Italy). This system consists of six video cameras detecting infrared reflecting markers (spheres of 5-mm diameter) at a sampling rate of 120 Hz. Spatial resolution of the system is 0.3 mm. The infrared reflective markers were attached to the nail of the participant's right thumb and index finger, and another marker was attached to the participant's right wrist. The markers attached to the thumb and index finger were used to analyse the grasp kinematics, whereas the marker attached to the wrist was used to analyse the kinematics of reaching and lifting. The data of

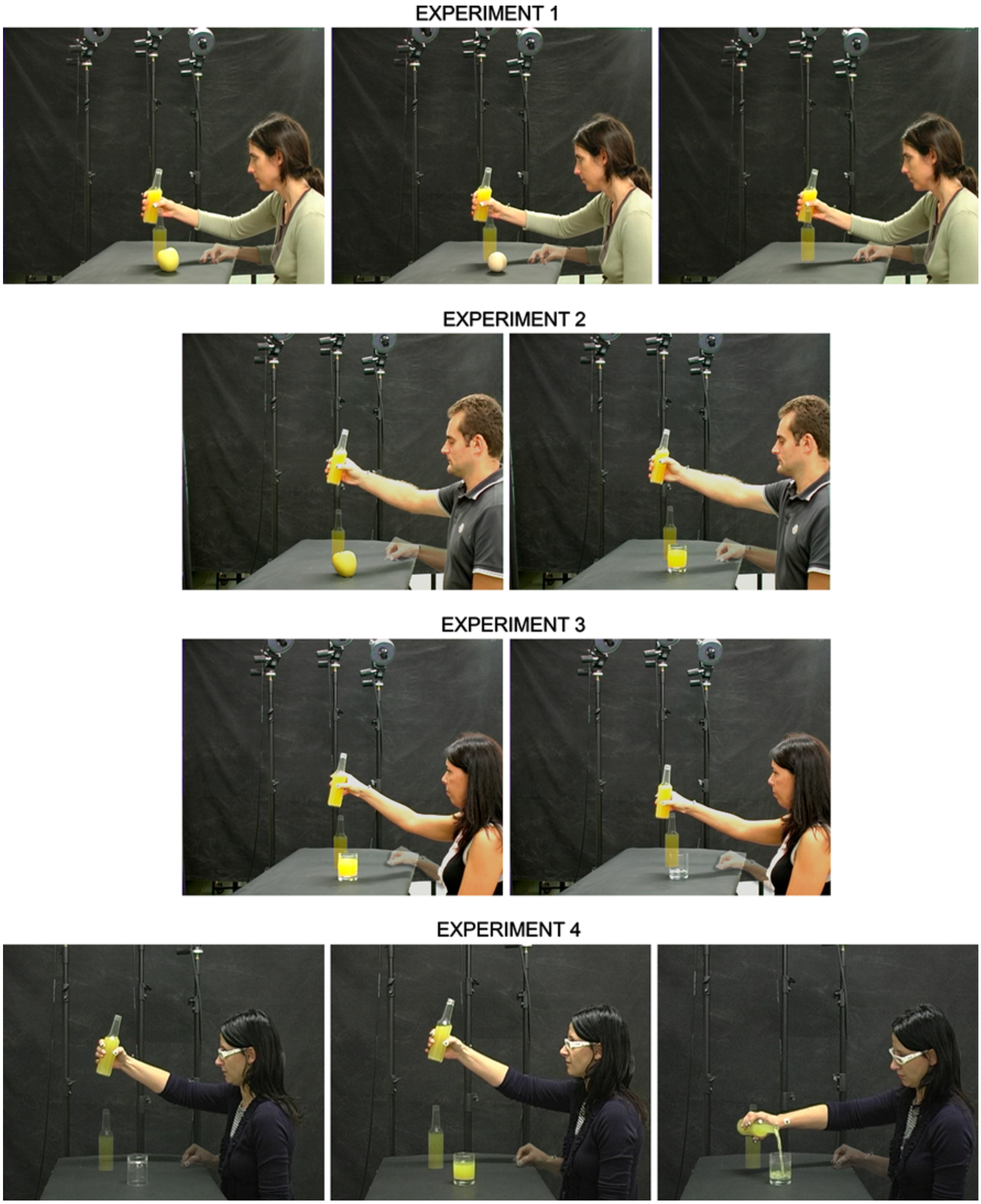

Fig. 1 Experimental set-up and stimuli presented in experiments 1–4. Examples of the movements executed by the participants in the four experiments are shown

the recorded movements were analysed using a software developed using MATLAB version 7.7 (R2008b). Recorded data were filtered using a Gaussian low pass smoothing filter (sigma value, 0.93). The time course of reach-grasp and lift was visually inspected: the beginning of the grasp was considered to be the first frame in which the distance between the two markers placed on the right finger tips increased more than 0.3 mm (spatial resolution of the recording system) with respect to the previous frame. The end of the grasp was the first frame after the beginning of finger closing in which the distance between the two right fingers decreased less than 0.3 mm with respect to the previous frame. The beginning of the reach was considered the first frame during which the displacement of the reach marker along any Cartesian body axis increased more than 0.3 mm with respect to the previous frame. To determine the end of the reach we calculated, separately for the X, Y and Z axes, the first frame following movement onset in which the X, Y and Z displacements of the reach marker decreased less than 0.3 mm compared to the previous frame. Then, the frame endpoint temporally closer to the grasp end frame was chosen as the end of the reach. The frame immediately successive to the reach end was considered as the lift beginning, while the lift end corresponded to the frame in which the highest point of the hand trajectory was reached during lifting.

The grasp was studied by analysing the time course of the distance between the index finger and thumb markers. From a pinch position, the grasp component is constituted by an initial phase of finger opening up to a maximum (maximal finger aperture) followed by a phase of finger closing on the object (Jeannerod 1988). We measured the following grasp parameters: peak velocity of finger closure and peak acceleration of finger closure. Concerning the reach, we measured reach peak velocity and reach peak acceleration. Concerning the lift, we analysed the maximal curvature of the lift trajectory along the lateral axis (left-to-right, z-axis) of the participants. The maximal curvature is defined as the maximal distance (on the z-axis) of the wrist trajectory from the straight line connecting the beginning and end of lift.

Data analysis

Repeated measures ANOVAs were carried out on the mean values of the grasping-reaching-lifting parameters. The within-subjects factor was distractor (no distractor vs sphere vs apple). In all analyses, post hoc comparisons were performed using the Newman–Keuls procedure. The significance level was fixed at $p = 0.05$. When a factor was significant, we also calculated the effect size [η^2_p (partial)].

Results and discussion

The closing phase of the grasp was affected by the presence of the distractors. Indeed, peak acceleration of finger closure was significantly lower when the two distractors were presented [($F(2,14) = 3.99$, $p = 0.042$, $\eta^2_p = 0.4$]. Post hoc analysis showed a significant difference between the no-distractor condition and the conditions of presentation of the sphere and apple ($p = 0.035$ and $p = 0.05$ respectively, Fig. 2). Post hoc analysis also showed no significant difference between apple and sphere ($p = 0.84$). Arm peak acceleration was affected by factor distractor, decreasing when either the sphere or the apple was presented [$F(2,14) = 5.12$, $p = 0.021$, $\eta^2_p = 0.4$, post hoc test, $p = 0.017$ and $p = 0.033$ respectively, Fig. 2]. Post hoc analysis also showed that there was no significant difference between the apple and the sphere ($p = 0.9$). Z maximal curvature during lifting was affected by the presence of the distractors [$F(2,14) = 4.24$, $p = 0.036$, $\eta^2_p = 0.4$, Fig. 2]. Post hoc analysis showed that when either the apple or the sphere was presented, subjects' trajectory deviated to the right, that is in the opposite direction with respect to the distractor position ($p = 0.047$ and $p = 0.03$ respectively). No significant difference was found between the two distractors (post hoc test, $p = 0.78$). Other results are reported in Table 1.

The results of the present experiment suggest that the sequence of reaching-grasping and lifting was interfered by the presence of both the apple and the sphere since the grasp and reach slowed down and the lift trajectory veered away from the distractor. However, this interference seemed to be independent from the semantic category of the distractor. This can be explained by the fact that even if the sphere was a manipulable artefact as the bottle was, it was not an artefact with any specific function of interaction with the bottle. The sphere was placed in a background (the table) so that the thematic spatial relationships with the bottle were weaker than the apple because they were less frequent. Nevertheless, concerning the thematic spatial relationships with the bottle, no different interference effect was found between apple and sphere. Consequently, the interference could be based on motor programmes which, for both the sphere and the apple, took into account extrinsic and intrinsic object properties (structural affordances).

Experiment 2

In experiment 2, we addressed the problem of whether an artefact distractor, that is a glass, potentially compatible, from a functional point of view, with the artefact target, that is a bottle, induced interference. Moreover, we tested whether the actuality of the functional compatibility of the distractor played a role in inducing interference. We presented as distractors the following objects: a glass filled with orange juice (compatible artefact object) and an apple (the natural object presented in experiment 1). As a matter of fact, the glass was semantically and functionally compatible with the bottle, but, being filled, actually it was not.

Methods

Participants

A new sample of eight right-handed (Oldfield 1971), naïve volunteers (4 women and 4 men, age 20–29 years) took part in the experiment.

Apparatus, stimuli and procedure

Apparatus and procedure were the same as in experiment 1. The distractors were the yellow apple presented in

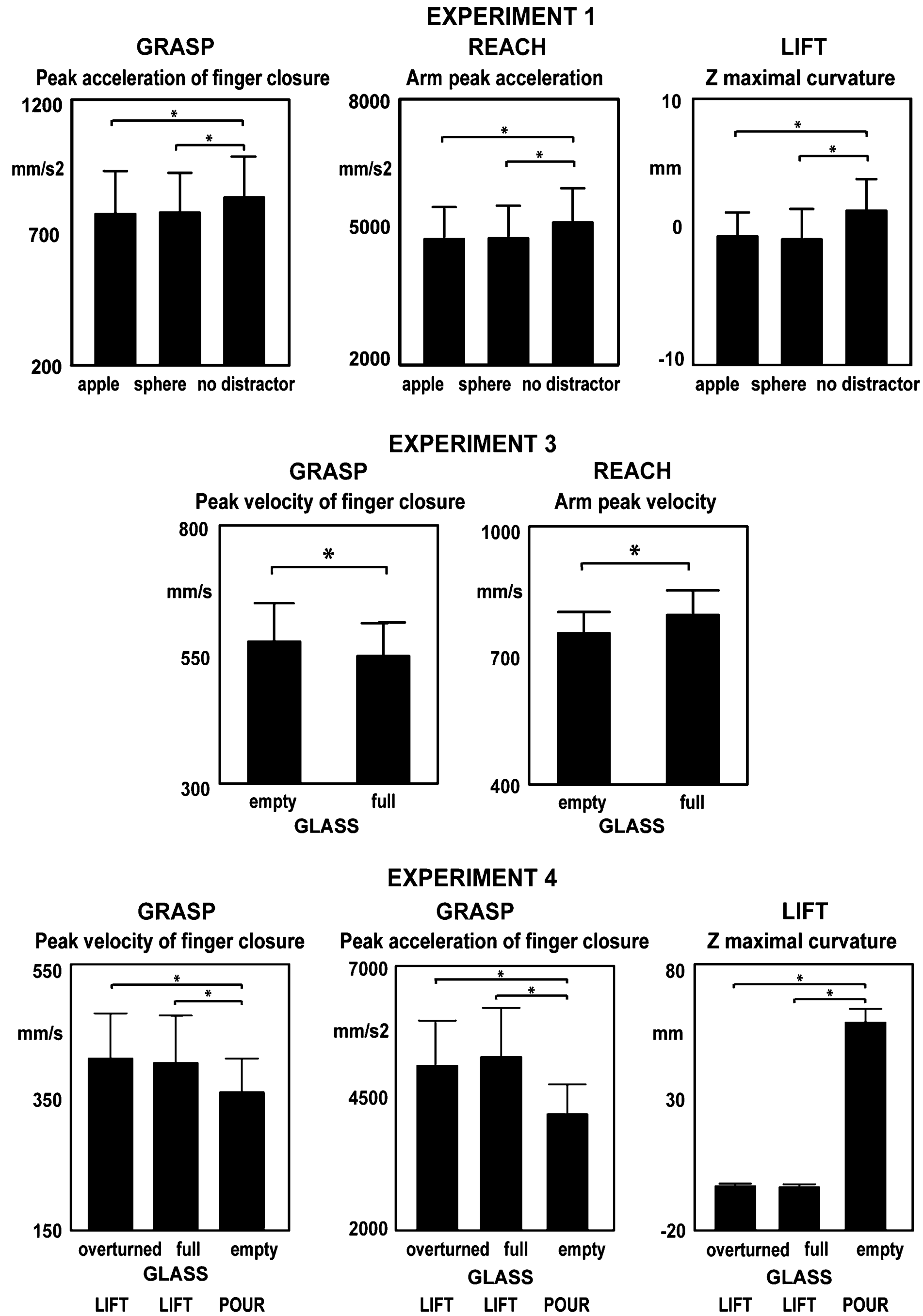

Fig. 2 Kinematic parameters of grasp, reach and lift collected in experiments 1–4, which resulted significant in the ANOVAs. *Bars* are SE. In the panel showing Z maximal curvature, *positive* and *negative* values refer to movements directed to the *left* and to the *right*, respectively

experiment 1 and a glass (∼7 cm width, ∼8 cm eight) filled with orange juice (Fig. 1). The no-distractor condition was not included in the procedure; consequently, the experimental session consisted of a single block of 30 trials.

Data recording and analysis

Data recording and analysis were the same as in experiment 1. Repeated measures ANOVAs were carried out on mean values of the grasping-reaching-lifting parameters, considering as within-subjects factor distractor (apple vs filled glass). The significance level was fixed at $p = 0.05$.

Results and discussion

No differences were found between the kinematics of the sequence directed to the bottle when the apple and the filled glass were presented (Table 1). The glass, although of the same category and functionally compatible with the bottle, could not induce an interference different from that of the

Table 1 Results of ANOVAs performed on kinematic parameters

	Grasp		Reach		Lift
	Peak velocity of finger closure	Peak acceleration of finger closure	Arm peak velocity	Arm peak acceleration	Z maximal curvature
Experiment 1	$F(2,14) = 2.2$	$F(2,14) = 3.99$	$F(2,14) = 1.06$	$F(2,14) = 5.12$	$F(2,14) = 4.24$
Distractor levels: null versus apple versus sphere	$p = .146$	$p = .042$	$p = .371$	$p = .021$	$p = .036$
	n.s.	$\eta_p^2 = 0.4$	n.s.	$\eta_p^2 = 0.4$	$\eta_p^2 = 0.4$
		Figure 2		Figure 2	Figure 2
Experiment 2	$F(1,7) = 1.23$	$F(1,7) = 0.11$	$F(1,7) = 0.98$	$F(1,7) = 0.77$	$F(1,7) = 1.08$
Distractor levels: apple versus filled glass	$p = .304$	p = .746	p = .358	$p = .409$	$p = .332$
	n.s	n.s	n.s	n.s	n.s
Experiment 3	$F(1,7) = 16.13$	$F(1,7) = 2.44$	$F(1,7) = 14.58$	$F(1,7) = 3.74$	$F(1,7) = 1.51$
Distractor levels: filled versus empty glass	$p = .005$	$p = .162$	p = .007	$p = .094$	$p = .258$
	$\eta_p^2 = 0.7$	n.s.	$\eta_p^2 = 0.7$	n.s.	n.s.
	Figure 2		Figure 2		
Experiment 4	$F(2,14) = 4.05$	$F(2,14) = 4.66$	$F(2,14) = 1.08$	$F(2,14) = 1.7$	$F(2,14) = 126.1$
Object levels: overturned versus filled versus empty glass	$p = .041$	$p = .028$	$p = .365$	$p = .218$	$p < .0001$
	$\eta_p^2 = 0.4$	$\eta_p^2 = 0.4$	n.s.	n.s.	$\eta_p^2 = 0.9$
	Figure 2	Figure 2			Figure 2

The factor was distractor or object

apple. This can be explained by the fact that the glass was filled with juice and consequently, actually, it could be not filled anymore. In other words, it was potentially compatible with the bottle from a functional point of view, but actually it was not. Note that the thematic spatial relationships of the bottle with the glass are stronger than those with the apple, because a bottle is more frequently presented with a glass than with an apple. Nevertheless, no different interference effect was found between glass and apple.

Experiment 3

We compared the effects of a distractor that actually was functionally compatible with the bottle (an empty glass) with those of the same distractor actually not compatible (a glass filled with orange juice).

Methods

Participants

A new sample of eight right-handed (Oldfield 1971), naïve volunteers (5 women and 3 men, age 23–28 years.) took part in the experiment.

Apparatus, stimuli and procedure

Apparatus and procedure were the same as in experiment 2. The distractors were the glass either filled with orange juice or empty (Fig. 1).

Data recording and analysis

Data recording and analysis were the same as in experiment 2. In the repeated measures ANOVAs, the levels of the within-subjects factor distractor were filled glass versus empty glass.

Results and discussion

Peak velocity of finger closure was affected by distractor. The participants closed their fingers faster when the empty glass was presented as compared to the filled glass [$F(1,7) = 16.13$, $p = 0.005$; $\eta_p^2 = 0.7$, Fig. 2]. Arm peak velocity was lower when the empty glass was presented [$F(1,7) = 14.58$, $p = 0.007$; $\eta_p^2 = 0.7$, Fig. 2]. Other results are reported in Table 1.

The effects of the presentation of an empty glass on grasp and reach as compared to a filled glass could be consequent to the effects of an automatically activated programme of pouring. In order to test whether this could be the case, we compared the kinematics of a sequence of pouring orange juice contained in a bottle into a glass with those of lifting the bottle.

Experiment 4

Methods

Participants

A new sample of eight right-handed (Oldfield 1971), naïve volunteers (4 women and 4 men, age 22–29 years.) took part in the experiment.

Apparatus, stimuli and procedure

Apparatus and procedure were the same as in experiment 2. The participants were required to reach-grasp and lift the bottle when a glass filled with orange juice or an overturned glass was presented. When an empty glass was presented, they were required to reach-grasp and pour the orange juice contained in the bottle into the glass (Fig. 1).

Data recording and analysis

Data recording and analysis were the same as in experiment 2. The lift end corresponded to the frame in which the highest point of the pour and lift trajectory was reached. In the ANOVAs, the levels of the within-subjects factor object were empty glass (to pour) versus filled glass (to lift) versus overturned glass (to lift).

Results and discussion

Peak velocity [$F(2,14) = 4.05, p = 0.041, \eta_p^2 = 0.4$, Fig. 2] and peak acceleration [$F(2,14) = 4.66$, $p = 0.028$, $\eta_p^2 = 0.4$, Fig. 2] of finger closure decreased when grasping with the intention of pouring. Post hoc analysis showed that the two parameters were significantly lower when pouring than lifting (peak velocity: filled glass, $p = 0.039$, overturned glass $p = 0.05$; peak acceleration $p = 0.034$ and $p = 0.03$). The two conditions of lifting did not differ from each other (peak velocity $p = 0.74$; peak acceleration $p = 0.67$). As expected, the Z maximal curvature was greater in the pouring than in the lifting [$F(2,14) = 126.1$, $p < 0.0001$, $\eta_p^2 = 0.4$, post hoc test $p = 0.0002$ for the both conditions of lifting, Fig. 2]. No statistical difference was found between the two conditions of lifting ($p = 0.93$).

The finding that peak velocity of finger closure was lower during grasping for pouring indicates that the grasp was more accurately executed in order to allow a more stable holding during a successive pouring. In addition, this datum leads us to speculate that inhibition of the pouring programme in experiment 3 could have produced an increase in this parameter. This effect could be considered as equivalent to trajectory deviation away from distractor found in the present and previous studies (e.g. Tipper et al. 1991, 1997). Moreover, inhibition during reach in order to pour interfered with movement execution by slowing down it.

General discussion

The present study aimed at determining whether, in a task of reaching-grasping and lifting an artefact, the presentation of another artefact, functionally compatible with the target, automatically activated a programme of interaction between the two objects, which modified the kinematics of an actual different sequence.

In experiment 1, we compared the effects of two distractors belonging to different semantic categories (artefact, i.e. a sphere and natural object, i.e. an apple) on the kinematics of reaching-grasping and lifting the bottle (an artefact target). The reach and grasp components slowed down in comparison with the condition of no-distractor presentation, and, in addition, the trajectory of hand lifting veered away from distractor position. These results are in agreement with previous studies (e.g. Tipper et al. 1991, 1997), which hypothesized an encoding of distracting stimuli in terms of action-based representations. These representations were inhibited during selection of the target and interfered with ongoing movement.

No difference in interference effect was observed between natural and artefact distractors. This result seems to be at odds with those by Kritikos et al. (2001). These authors manipulated size and semantic category of the distractors and found an effect of both of these characteristics on grasp. However, two main differences should be observed between the stimuli presented in the present study and those by Kritikos et al. (2001). First, in the present study, the distractors were approximately of the same size, whereas distractors of different size were presented in Kritikos et al.'s study (2001). Second, in the present study the distractors were never used as targets, whereas this occurred in Kritikos et al.'s study (2001). Thus, the fact that interfering programmes varied according to distractor size and the same distractors were also actually grasped could increase the probability to make evident an effect of the category which could be under-threshold for distractors of fixed sizes. Finally, it is important to stress that the main purpose of the present study was not to compare the effects between distractors of different semantic categories, but the effects of artefact distractors, which, when functionally compatible with an artefact target, could activate programmes of interaction affecting the actual action directed to the target.

The results of experiments 2 and 3 showed that, actually, target and distractor should be functionally compatible in order to affect the action directed to the target. Indeed, a programme of pouring could be activated when a bottle was presented with a functionally compatible distractor, that is an empty, rather than a filled glass. Concerning the grasp, in experiment 3, the finger closure on the empty glass was quicker. We can speculate that this was due to the fact that a programme of pouring was inhibited. Indeed, in experiment 4, finger closure was slower when the reaching-grasping was finalized to pour. Inhibition of pouring in experiment 3 might have produced an inverse effect of faster grasping.

Tools are tightly coupled to different sequences of actions characterizing their use; for example, a bottle filled with liquid can be associated with an action of pouring, drinking from the bottle, or placing into an ice bucket. In other words, sequences of arm and hand actions can develop and become strongly associated with tools following experience of their use. This well-defined set of action operations is tied to prior experience and is stored as knowledge of object functions (Valyear et al. 2007). We propose to use the term working affordance to define the programme representing a specific sequence of actions during which an artefact and a functionally compatible object interact with each other. The term working affordance would indicate a programme of interaction among artefacts depending not only on intrinsic and extrinsic properties of objects, but also on stored information about learned hand–object relations. These representations are complementary to those mediating visuomotor transformations (structural affordances) underlying grasping actions. For these reasons, when two artefacts are present in a scene, the resulting action is strictly linked to the functional compatibility (e.g. a bottle and a glass, or a nut and a nutcracker), to the suitability (i.e. to be in the right place at the right time) and, in particular, to the actual state of the artefact (i.e. empty or full; with or without the nutshell). A neuroimaging and EEG study (Mizelle and Wheaton 2010) has shown that the contextual correctness/incorrectness of tool–object interaction activated distinct brain regions. Specifically, incorrectness activated temporal area, cingulate area and insula, whereas correctness activated parietal and frontal areas. Activation for incorrectness preceded correctness. These data are in accordance with the concepts of compatibility, suitability and actual state of artefacts proposed for working affordances. Indeed, Mizelle and Wheaton (2010) suggested that activation of insula and superior temporal cortex may serve as a "gatekeeper", for the evaluation of the contextual correctness of possible interactions between presented artefacts (e.g. bottle with empty glass). Once the correctness was verified, the fronto-parietal areas were activated in order to derive the adequate sensorimotor representation and motor plan for that artefact–action goal pair. In the case of incorrectness, the insula/superior temporal areas might serve to generate signals allowing for appropriate perception of tool use error. Thus, we can expect a fronto-parietal activation when a bottle was presented with an empty glass, and a insula/superior temporal area activation when the bottle was presented with a full glass.

The function of the bottle or the glass might be considered that of liquid container only. Nevertheless, the simple function to contain a liquid is not the only reason why these artefacts are made. The reason for making them is the intention of using them for pouring or drinking. In this sense, a working affordance would reflect the possibility to prepare a sequence of actions according to a final intention (e.g. lifting the bottle with the intention of filling the empty glass) and on the basis of motor experience (e.g. simulating a sequence based on motor experience rather than visual salience, Pezzulo et al. 2010). The working affordance not only influences object detection (functional affordance) as found by Riddoch et al. (2003) but it implicitly changes parameters of the sequence even in the absence of any explicit task to use the objects (target and distractor) together. Following this hypothesis, a working affordance would be activated whenever a target-artefact is presented even with natural objects as long as the two objects are functionally compatible. For example, grasping a knife in the presence of an apple may more easily activate a programme of peeling. This raises the possibility that objects of whatever category (artefact or natural object) presented with an artefact target may contribute to evoke working affordances.

Neurophysiological studies have described a number of areas within the frontal and the posterior parietal cortex that is involved in the control of actions executed with tools (Culham and Valyear 2006; Valyear et al. 2007). These tool-related imaging studies reported activation of anterior portion of the intraparietal sulcus (IPS), inferior parietal lobule, ventral premotor cortex (VPM) (Binkofski et al. 1999; Chao and Martin 2000; Johnson-Frey 2004; Kellenbach et al. 2003; Gerlach et al. 2002; Grabowski et al. 1998), medial fusiform gyrus (Beauchamp et al. 2002, 2003; Chao et al. 2002; Devlin et al. 2005; Whatmough et al. 2002). Therefore, it is possible to suppose that tools can activate a parietal-frontal circuit including parietal lobe, IPS and VPM; this circuit seems to be involved on motor planning and on motor execution. Ideomotor apraxia (IM) is often associated with parietal lesions, specifically regions encompassing parts of the IPS (Buxbaum et al. 2005; Haaland et al. 2000). IM patients poorly perform on tasks associated with planning artefact-related movements; they are characterized by the inability, once they recalled the mental representation of movement required, to activate the correct motor sequence to implement the movement itself: the patient knows "what" to do, but he does not know "how" to do it. Thus, we can expect a deficient retrieval of specific interactions between functionally compatible artefacts (Buxbaum et al. 2003).

Conversely, neuropsychological studies conducted on patients with damage to the frontal lobes showed "utilization behaviour" (Lhermitte 1983): in these patients, an object elicits a stereotyped action, inappropriate in the context. For example, if there is a glass within the reach of the patient, he will grasp it; if a bottle of water is also placed on the desk, he will grasp this too and then will pour water into the glass and will drink it. The same occurs also when the patients have been instructed to carry out other tasks (Shallice et al. 1989). A possible explanation for this behaviour is that the inhibitory function of the frontal lobes on the parietal lobes is suppressed; the result is a lack of inhibition mechanism on the parietal lobes, including the areas specialized for the control of actions executed with tools. In other words, patients with damage to the frontal lobes are unable to control the working affordances induced by two or more functionally compatible artefacts. Consequently, we expect a lack of working affordances in apraxic patients, and, conversely, an insufficient control of them in patients with prefrontal lesions.

Summing up, these data support the idea that when two artefacts are presented in a scene, they do not only automatically and obligatorily activate the affordance that they usually can afford when presented alone. In fact, our results provide evidence for the notion that the processing of artefact features depends on the contextual information. As contextual information, we refer to objects that are functionally compatible with the target and activate specific (working) affordances related to the potential interaction of the target with the objects presented in the scene.

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