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ORIGINAL ARTICLE

Do already grasped objects activate motor affordances?

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Abstract

This study investigated whether in a stimulus–response compatibility (SRC) task affordance effects in response to picture of graspable objects emerge when these objects appear as already grasped. It also assessed whether the observed effects could be explained as due to spatial compatibility between the most salient part in the object/display and the hand of response rather than to action potentiation. To this aim, we conducted three behavioural experiments in which participants were required to discriminate the vertical orientation (upright vs. inverted) of an object presented in the centre of the screen, while ignoring the right–left orientation of its handle. The object could be presented alone, as already grasped, as partially masked (Experiment 1) or with a human hand close to its graspable side (Experiment 2). In addition, to assess the role of perceptual salience, the object could be presented with a human hand or a non-biological (a geometrical shape) distractor located opposite to the object's graspable side. Results showed faster responses when the object's handle was located on the same side of the responding hand with a larger effect when upright objects were shown as already grasped (Experiment 1) or when a hand was displayed close to its handle (Experiment 2), and a smaller reversed effect when the hand or the geometrical shape was located opposite to the handled side (Experiment 3). We interpreted these findings as indicating that handle orientation effects emerging in SRC tasks may result from the interplay between motor affordance and spatial compatibility mechanisms.

Introduction

In the last years, there has been an increasing number of studies investigating which features affect how we process and respond to objects. The empirical evidence collected so far seems to indicate that the perception of an object activates a series of actions congruent with some of its visual properties, such as size, orientation, and the orientation of eventual graspable parts (e.g., Bub & Masson, 2010; Masson, Bub, & Breuer, 2011; see Borghi & Riggio, 2015 for a review). These objects' features, defined by Ellis and Tucker (2000) as micro-affordances, are central in guiding our actions even when actual interactions with the object are not required. For instance, in laboratory settings using a stimulus–response compatibility (SRC) paradigm, Tucker and Ellis (1998) showed that if participants are required to decide whether a depicted object is presented in a canonical or inverted orientation, motor responses are facilitated when they are compatible with the action required to interact with the object, such as grasping it with the right hand, as compared to when they are incompatible. This effect, also known as handle orientation effect, has been widely replicated in behavioural experiments employing tasks that require assess to semantic object knowledge (e.g., Iani, Baroni, Pellicano, & Nicoletti, 2011; Ottoboni, Iani, Tessari, & Rubichi, 2013; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; Riggio et al., 2008) and in a recent electrophysiological study by Goslin and colleagues (Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012). Consistently, it has been shown that the observation of graspable objects is accompanied by activation in brain areas implicated in object manipulation (e.g., Chao & Martin, 2000; Gazzola, & Keysers, 2009), while transcranial magnetic stimulation (TMS) studies showed greater motor excitability in the affording effector when observing manipulable objects (Buccino, Sato, Cattaneo, & Riggio, 2009; Franca et al., 2012) thus supporting the view that the

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representation of objects involves the activation of motor-related information.

Importantly, the emergence of these “affordance effects”[1] seems to be modulated not only by objects’ features but also by the physical and social context within which actions are performed. For instance, affordance effects are affected by the observation of actions performed by other agents (e.g., Maranesi, Bonini, & Fogassi, 2014; Borghi et al., 2006; Bach, Bayliss, & Tipper, 2010; Ellis et al., 2013), by the specific context within which they should be performed (e.g., Fini, Brass, & Committeri, 2015) and by the observer’s actual possibility to interact with the observed object (e.g., Buccino et al., 2009; Cardellicchio, Sinigaglia, & Costantini, 2013; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). As regards this latter point, in a first behavioural study, Costantini et al. (2010) showed that hand responses were facilitated when congruent with the orientation of the object’s handle only when the object was perceived as reachable. In a follow-up TMS study, Cardellicchio et al. (2013) stimulated the left primary motor cortex while participants observed graspable and non-graspable objects located within or outside their own reachable space. They found higher motor evoked potentials (MEPs) for graspable objects falling within the reachable space compared to either a non-graspable object or a graspable object falling outside the participant’s reachable space. Using the same technique, Buccino et al. (2009) investigated the excitability of the primary motor cortex while participants observed objects whose handle could be intact or broken and found that MEPs were larger only when the handle was intact. Overall these studies are consistent with the idea that during passive observation, our motor system automatically processes physical and environmental factors constraining action execution, and underline the importance played by contextual information in the emergence of affordance effects.

It is important to consider that objects are rarely presented in isolation, and some information in the environment may be conflicting. Specifically, an object can suggest a specific action because it presents certain features, such as a handle affording a grasping action with the right hand; however, the execution of the elicited action may not be actually possible not only because the observer cannot actually act but also because, as an example, another agent already holds the object. In such a situation, the activation of a grasping action would not be useful. At the same time, the observation of a hand holding an object may serve as a motor prime that either evokes the simulation of the action (e.g., Borghi et al., 2006), possibly due to the activation of the mirror neuron system (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Gallese, Gernsbacher, Heyes, Hickock, & Iacoboni, 2011) or the activation of a complementary action (e.g., Ellis et al., 2013; Ferraro et al., 2012; Sartori, Cavallo, Bucchioni & Castiello, 2012). Which information will affect the observer? We believe the studies conducted so far do not allow us to unequivocally isolate which contextual information, among the multiple conflicting ones available to the observer, affects the final behaviour.

Crucially, the idea that individuals activate motor programs when viewing manipulable objects, the so-called affordance view, is recently under dispute. Some authors have pointed out that the presence of an object’s graspable part creates a visual asymmetry within the stimulus display that captures attention (e.g., Anderson, Yamagishi, & Karavia, 2002; Matheson, Newman, Satel, & McMullen, 2014; Matheson, White, & McMullen, 2014). As a consequence, a left/right spatial code is created for this salient part and, due to the dimensional overlap between stimulus and response spatial codes (e.g., Kornblum, Hasbroucq, & Osman, 1990), it facilitates the responses made with the spatially corresponding hand. According to this view, the effect observed by Tucker and Ellis (1998) is in fact a stimulus–response (S–R) spatial correspondence effect (location coding account; Cho & Proctor, 2010, 2011, 2013; Lien, Jardin, & Proctor, 2013). At present, both views collected experimental support and it seems plausible to believe that the observed handle orientation effects, at least in those studies employing the SRC paradigm, may result from a combination of mechanisms (e.g., Iani et al., 2011; Riggio et al., 2008; Saccone, Churches, & Nicholls, 2016).

Given the considerations reported above, the main aim of this study was to investigate the role of different types of features of the observed objects and of the physical context in affecting performance. To this end, we conducted three behavioural experiments employing the SRC paradigm in which participants were required to discriminate the vertical orientation (upright vs. inverted) of an object presented in the centre of the screen and with a graspable part congruent with either a left or a right grasp. We assessed whether motor responses were affected by the irrelevant left–right orientation of the object’s graspable part (i.e., the handle). In the different experiments we manipulated how the target object was presented. More precisely, in Experiment 1, to assess whether the motor system takes into consideration whether the object is potentially graspable, the object could be presented alone (object-only condition) or as already grasped by a human hand (grasped-object condition). In addition, to assess whether perceptual salience could affect the results, we

[1] Throughout the manuscript we use the term “affordance effect” when referring to the possible influences on performance exerted by action-related objects’ features, while we use the term “handle orientation effect” when referring to handle–response correspondence effects.

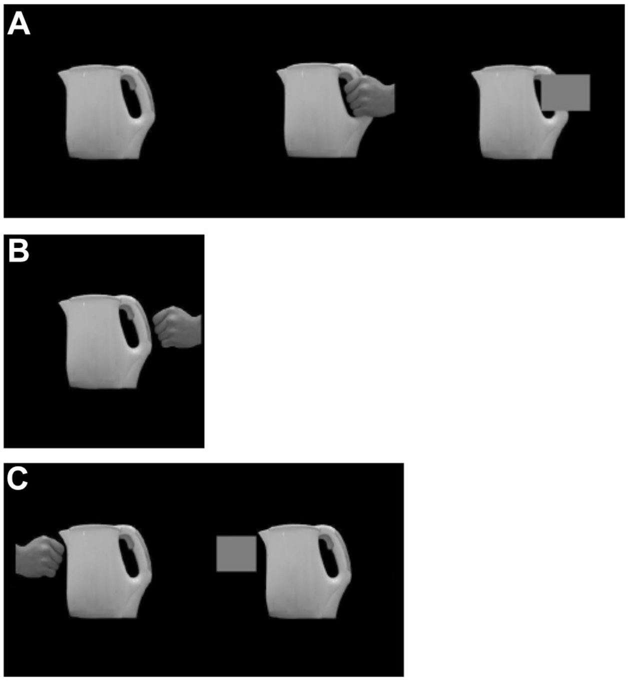

Fig. 1 Example of one of the objects (a kettle) used in the three experimental conditions of Experiment 1 (object-only, grasped-object and masked-handle conditions, respectively; panel **a**), in Experiment 2 (panel **b**) and in the two experimental conditions of Experiment 3 (opposite-hand and opposite-square conditions, respectively; panel **c**). The object is presented in its upright orientation

included a condition in which the object graspable part was partially masked (masked-handle condition) (Fig. 1, panel a). If the activation of the motor system during object observation depends on the observer's opportunity of interacting with it, then a handle orientation effect, that is faster response times when responses are congruent with the right–left orientation of the object's graspable part, should emerge when the object is presented alone. However, an object that is already held should not potentiate motor actions that are compatible with a grasping action. As a consequence, no handle orientation effect should emerge. Alternatively, the observation of a hand holding the object may activate a simulation of the action. In this case, the handle orientation effect should be amplified for the grasped-object condition as compared to the object-alone condition. If perceptual salience plays a role in the emergence of handle orientation effects, then no difference should be evident between the grasped-object and the masked-handle conditions. Experiment 2 was aimed at assessing whether the same results are obtained when the hand does not grasp the object's handle but is close to it (Fig. 1, panel b). Finally, Experiment 3 was aimed at assessing whether performance is affected when either a human hand or a geometrical shape is presented opposite to the handle side (Fig. 1, panel c).

Experiment 1

As discussed in "Introduction", studies employing a SRC paradigm consistently showed that, when the task requires to process the object's identity, responses are faster when they are congruent with the right–left orientation of the object's graspable part (e.g., Tucker & Ellis, 1998). This result has been interpreted as due to the activation of motor programs of the action most suited to interact with the object. An open question is whether this effect is present even when the observed object could not be potentially grasped because someone else is already grasping it. The aim of Experiment 1 was to assess whether seeing an object grasped by a human hand activates the same motor information triggered by the observation of the object alone. To this end, participants were required to press one of two lateralized response keys according to the vertical orientation (i.e., upward or inverted) of a graspable object presented in the centre of the screen while ignoring the left–right orientation of its graspable part. In the object-alone condition, the object was always presented as "free", while in the grasped-object condition the object was always presented with a human hand holding the handle. To exclude that differences between these two conditions could be due to differences in visual asymmetry and salience, we included a third condition in which the hand grasping the object was replaced with a geometrical shape (a filled square) covering part of the object's graspable part (masked-handle condition). In this way, the stimulus presented the same perceptual asymmetry of the grasped-object condition.

If the motor system processes environmental factors constraining action execution and action representations are activated only if the observer is in the position to potentially interact with the object (e.g., Costantini et al., 2010; Iani, Rubichi, Ferraro, Nicoletti, & Gallese, 2013), then the handle orientation effect, that is faster responses for handle–response corresponding trials, should emerge only in the object-only condition. On the other hand, if observing actions performed by other facilitates the execution of the same actions by the observer (e.g., Borghi et al., 2006; Brass, Bekkering, & Prinz, 2001), then the handle orientation effect should emerge also in the grasped-object condition and, as a consequence of motor priming, should be larger than the effect observed in the object-only condition. If this increased effect is due to the increased perceptual salience characterizing the grasped-object condition, a comparable increased effect should be evident also in the masked-handle condition.

Methods

Participants

90 undergraduate students (68 female, mean age = 20.28 years, SD = 1.49 years) from the University of Modena and Reggio Emilia took part in this experiment for course credit. All were right handed, reported normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment. This and the following experiments were conducted in accordance with the ethical standards laid down in the Declaration of Helsinki and fulfilled the ethical standard procedure recommended by the Italian Association of Psychology (AIP). All procedures were approved by the Department of Communication and Economics of the University of Modena and Reggio Emilia. All participants gave their written informed consent to participate to the study. Once selected, they were randomly assigned with equal probability to one of three experimental conditions (i.e., object-only, grasped-object, and masked-handle conditions).

Apparatus and stimuli

The experiment took place in a dimly lighted room. Participants sat in front of a 19″ monitor with a resolution of 640 × 480 pixels at about 60 cm from the screen. Stimuli presentation and response collection were controlled by the E-Prime software system version 2.0. The stimuli consisted of digital photographs of four different domestic objects (i.e., a watering can, a coffee pot, a jug and a kettle), presented in the centre of the screen. All images were rendered in grayscale and were of the same size (10.47° × 8.57°), irrespective of the size of the real objects. Objects could be presented upward or inverted (i.e., vertical orientation) with a leftward- or rightward-oriented handle. In the object-only condition, the object's handle was fully visible; in the grasped-object condition, stimuli were shown as already held by a human hand (i.e., two women's and two men's hands; 3.82° × 4.78°) with the back of the hand visible in both the upright and inverted orientations; finally, in the masked-handle condition the handle was covered by a geometrical shape occupying about the same area that in the grasped-object condition was covered by the hand (3.82° × 5.72°). In all experimental conditions, participants were instructed to respond according to the vertical orientation (upward or inverted) of the objects. Responses were executed by pressing the "z" or "-" key of a standard Italian keyboard with the left and right index fingers, respectively.

Procedure

Participants were tested individually in a single session. In all conditions, each trial began with a fixation point displayed at the centre of a black background for 1 s. Then the image of one object was centrally displayed for a maximum of 3000 ms or until the response occurred. Half of the participants in each experimental condition responded with a right button press ("-") to upward objects and with a left button press ("z") to inverted objects, whereas the other half experienced the opposite mapping. In handle–response corresponding trials, the handle position and the key for the correct response were on the same side (e.g., handle on the right, correct response on the right), whereas in handle–response non-corresponding trials, the handle was located on the opposite side with respect to the position of the correct response (e.g., handle on the left, correct response on the right). After a response was emitted, a blank screen was displayed for 600 ms. Instructions emphasized both speed and accuracy of response. However, no feedback was provided.

The experiment consisted of 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. An equal number of trials was provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and, for the grasped-object condition only, type of hand (two women's and two men's hands).

Results and discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (4.3% of the total trials) and incorrect responses (3.5% of the total trials) were excluded from the analyses.

For simplicity and in line with previous studies (e.g., Iani et al., 2011; Pappas, 2014; Saccone et al., 2016), data were collapsed based on the correspondence between handle orientation and response position (handle–response corresponding vs. handle–response non-corresponding trials). Correct RTs were then entered into a repeated-measures analysis of variance (ANOVA) with handle–response correspondence and object vertical orientation (upright vs. inverted) as within-participant factors and condition (object-only vs. grasped-object vs. masked-handle conditions) as between-participant factor. The respective data are shown in Table 1. Since a preliminary analysis showed that type of hand used in the grasped-object condition had no effect, this factor was not included in the following analyses.

Following significant interactions, comparisons were performed using the Bonferroni test for multiple comparisons.

The effect of condition was significant, $F(2,87) = 8.61$, $p < 0.001$, $\eta^2_p = 0.16$. Post hoc comparisons indicated that RTs were the slowest in the masked-handle condition (529 ms) than in the other two conditions (ps ≤ 0.001). No

Table 1 Mean RTs (and standard deviation) in ms in the three experimental conditions of Experiment 1 as a function of object vertical orientation (upright and inverted) and handle–response correspondence (corresponding and non-corresponding)

	Object only		Masked handle		Grasped object	
	Upright	Inverted	Upright	Inverted	Upright	Inverted
C	476 (54.1)	471 (49.2)	525 (69.3)	516 (63.2)	464 (57.0)	460 (58.3)
NC	487 (48.3)	483 (53.3)	543 (67.3)	533 (53.6)	500 (64.0)	482 (62.0)
Handle orientation effect	11	12	18	17	36	22

The handle orientation effect is computed as the difference in RTs between handle–response non-corresponding and corresponding trials

difference emerged between the object-only (479 ms) and the grasped-object (477 ms) conditions ($p = 0.84$).

The analysis also showed main effects of object vertical orientation, $F(1,87) = 8.26$, $p < 0.01$, $\eta^2_p = 0.09$, and handle–response correspondence, $F(1,87) = 80.49$, $p < 0.001$, $\eta^2_p = 0.48$, with faster responses for inverted (491 ms) than for upright stimuli (499 ms) and for handle–response corresponding (485 ms) than for non-corresponding (505 ms) trials. The two-way interactions between object vertical orientation and condition ($F > 1$) and between object vertical orientation and handle–response correspondence ($p = 0.14$) did not reach significance, while the interaction between condition and handle–response correspondence did, $F(1,87) = 5.86$, $p < 0.01$, $\eta^2_p = 0.12$. The difference between non-corresponding and corresponding responses was of 11 ms for the object-only condition, 17 ms for the masked-object condition and 29 ms for the grasped-object condition. Post hoc comparisons showed that the 11-ms handle–response correspondence effect evident in the object-only condition differed from the 29-ms effect evident in the grasped-object condition ($p = 0.002$), while it did not differ from the 17-ms effect evident in the masked-handle condition ($p = 0.46$). The effect evident in the grasped-handle condition did not differ from the effect evident in the masked-handle condition ($p = 0.11$).

The interaction between condition, handle–response correspondence and object vertical orientation did not reach significance ($p = 0.11$, $\eta^2_p = 0.05$). However, given the p and η^2_p values for this interaction and given the main effect of object vertical orientation, we decided to perform separate analyses for upright and inverted objects with handle–response correspondence as within-participant factor and condition (object-only vs. grasped-object vs. masked-handle conditions) as between-participant factor.

For upright objects, the analysis showed a main effect of condition, $F(2,87) = 7.85$, $p < 0.001$, $\eta^2_p = 0.15$. Post hoc comparisons showed that responses were the slowest in the masked-handle condition (534 ms, ps < 0.001), while they did not differ between the other two conditions (482 and 482 ms for the object-only and grasped-object conditions, respectively).

The main effect of handle–response correspondence was also significant, $F(2,87) = 57.69$, $p < 0.001$, $\eta^2_p = 0.40$, but it was modulated by Condition, $F(2,87) = 6.92$, $p < 0.01$, $\eta^2_p = 0.14$. Handle–response corresponding responses were 11 ms faster than non-corresponding ones in the object-only condition, 18 ms faster in the masked-handle condition and 36 ms faster in the grasped-object conditions. Post hoc comparisons showed that these effects were all significant and that the effect evident in the grasped-object condition differed from the effects evident in the object-only ($p = 0.002$) and masked-handle ($p = 0.03$) conditions. There was no difference between the object-only and the masked-handle conditions ($p = 0.94$).

For inverted objects, the analysis showed a main effect of condition, $F(2,87) = 8.31$, $p < 0.001$, $\eta^2_p = 0.16$. Post hoc comparisons showed that RTs were the slowest in the masked-handle condition (524 ms, ps < 0.001), while they did not differ between the grasped-object (471 ms) and object-only (477 ms) conditions. There were also a main effect of handle–response correspondence, $F(1,87) = 49.52$, $p < 0.001$, $\eta^2_p = 0.36$, with faster responses for corresponding (482 ms) than for non-corresponding (489 ms) trials. The interaction between handle–response correspondence and condition did not reach significance, $p > 0.21$, $\eta^2_p = 0.03$, meaning that the difference between handle–response corresponding and non-corresponding trials did not differ across conditions (12, 17 and 22 ms in the object-only, masked-handle and grasped-object conditions, respectively). Since for grasped objects only the handle–response correspondence effect was numerically larger for upright (36 ms) than for inverted (22 ms) objects, we compared the two effects by means of a paired-sample t test. The test confirmed that the effect evident in the grasped-object condition was significantly larger for upright than for inverted objects ($t_{29} = 2.48$, $p = 0.019$, Cohen's $d = 0.51$).

Contrary to our expectations, for both object vertical orientations, a significant handle orientation effect was present across conditions. The effect evident in the object-only condition was comparable in size to the effects reported in previous studies employing similar stimuli (e.g., Iani et al., 2011; Riggio et al., 2008). In line with the affordance view, this finding can indicate that the horizontal orientation of the graspable part of an object affects performance, even if this information is task irrelevant.

As regards the effect evident in the masked-handle condition, two alternative explanations may be proposed. First, it is possible that the effect emerged because of spatial coding of the stimulus' more salient part. Indeed, as in the object-only condition, the stimulus display was asymmetric, with the handle side being perceptually more salient than the other side of the object. Second, it is possible that the effect emerged because of the activation of a motor affordance. Since RTs in this condition were slower than in the other two conditions, it is possible that participants perceived the object as "incomplete" and perceptually completed it, thus producing the preconditions for the activation of a motor affordance (e.g., Grützner et al., 2010; Snodgrass & Feenan, 1990). These completion processes may require additional time (Murray, Sekuler, & Bennett, 2001) hence producing longer RTs. However, the results of the present experiment do not allow us to discriminate between these two explanations.

Crucially, the effect was evident even when objects were already grasped and, when the objects were upright, it was significantly larger than in the other two conditions. Such a finding does not support the view that the activation of the motor system during the observation of an object depends on the real possibility of interacting with it. Rather, it seems to suggest that observing a human hand holding an object activates the motor simulation of the observed action (e.g., Borghi et al., 2006; Jeannerod, 2001).

The observation that the handle orientation effect was significantly larger in the grasped-object condition as compared to the other two conditions only for upright stimuli allows us to exclude that the effect found for grasped objects is exclusively due to salience. If this were the case, the effect should not vary between upright and inverted objects, which are identical as regards salience/laterality. Rather, the finding of a larger effect for upright grasped objects is consistent with the idea proposed by Bub, Masson and Kumar (2017) that actions associated with the canonical description of an object may differ from those associated with how the object is presented, with competing action representations determining final performance. As regards our stimuli, it should be noted that when upright objects were shown as grasped the hand was depicted with a comfortable orientation. For inverted objects, the depicted grasping action presented an uncomfortable hand orientation that was, however, the one that ensured a confortable position at the end of the movement if the object had to be used and not only rotated (e.g., Rosenbaum et al., 1990). The selection of this uncomfortable hand orientation reflects what Rosenbaum and colleagues (1990) defined as second-order planning. This difference between upright and inverted objects could have caused the difference in the size of the handle–response correspondence effect.

Experiment 2

To test the generalizability of the results found in Experiment 1, in the present experiment we assessed whether the increased handle orientation effect is evident even when the hand does not grasp the object but it is close to its handle, with a pose congruent with the action of grasping it.

Methods

Participants

30 new right-handed undergraduate students (21 female, mean age = 21.37, SD = 1.94 years), selected as before, took part in this experiment for course credit.

Apparatus, stimuli and procedures

Apparatus, stimuli and procedures were the same as in Experiment 1, except for what follows. A human hand (two male and two female hands) was always presented with the object. The hand displayed the same pose as in the grasped-object condition of Experiment 1 and was presented on the same side of the handle, 5.7° from the centre of the object image.

The experiment consisted in 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. An equal number of trials was provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and type of hand (two women's and two men's hands).

Results and discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (4.3% of the total trials) and incorrect responses (3.7% of the total trials) were excluded from the analyses. Correct RTs were entered into a repeated-measures ANOVA with handle–response correspondence and object vertical orientation as within-participant factors. Since the variable type of hand had no effect, this factor was not included in the analysis. The respective data are shown in Table 2.

The analysis showed only a main effect of handle–response correspondence, $F(1,29) = 45.33$, $p < 0.001$, $\eta^2_p = 0.61$, with 31 ms faster responses in handle–response corresponding (475 ms) than in non-corresponding (506 ms)

Table 2 Mean RTs (and standard deviation) in ms in Experiment 2 as a function of object vertical orientation (upright and inverted) and handle–response correspondence (corresponding and non-corresponding)

	Upright	Inverted
C	478 (79.5)	473 (68.6)
NC	509 (86.2)	503 (72.8)
Handle orientation effect	31	30

The handle orientation effect is computed as the difference in RTs between handle–response non-corresponding and corresponding trials

trials. Neither object vertical orientation nor the two-way interaction involving handle–response correspondence and object vertical orientation reached statistical significance (Fs < 1).

This result may indicate that both viewing a hand grasping an object's handle and viewing a hand displaying a pose congruent with grasping it activate the motor program of the action most suited to interact with the object. This result seems to be consistent with the view that this activation is triggered not only when we observe somebody else acting on an object but also when we see somebody else close to an object (see Bach, Nicholson & Hudson, 2014 for a review). According to the affordance-matching hypothesis proposed by Bach et al. (2014) this occurs because seeing somebody else acting on an object or in the vicinity of it brings to the retrieval of the object's function and manipulation knowledge. Furthermore, this finding, along with the findings evident for the grasped-object condition of Experiment 1, is also consistent with the view that actions may be triggered not only by the observation of someone else's action but also by the representation of the to-be-expected effects suggested by an action (e.g., Hommel, 2009; Hommel, Müsseler, Aschersleben, & Prinz, 2001). In other words, seeing a hand close to the object may activate the anticipation of the effects of the action thus producing the same effects evident when the end state of the action is observed. Different from Experiment 1, in this experiment the handle–response correspondence effect did not vary as a function of object orientation. This could be due to the fact that in this experiment the hand was displayed as approaching the object but the final state of the action (that for inverted objects would have corresponded to an uncomfortable hand orientation) was not depicted.

Experiment 3

The hand, as other body parts, is a salient biological stimulus that can automatically capture attention (e.g., Morrisey & Rutherford, 2013). Hence, the increased handle orientation effect observed in the grasped-object condition of Experiment 1 with upright objects and in Experiment 2 could be due to the presence of the hand itself rather than to the action primed by it. Also, since the orientation of the hand was always congruent with the upward or downward orientation of the object, it is possible that participants paid attention to the hand to decide whether the object was upright or inverted. Directing attention to the hand could then lead to the activation of a spatially compatible response (e.g., Cho & Proctor, 2010, 2011). To test these hypotheses, in the present experiment the object was always displayed along with a distractor positioned on the opposite side as the object's handle. For half of the participants, the distractor was the human hand used in Experiment 2, while for the other half it was the same geometrical shape used in the masked-handle condition of Experiment 1. If the hand captures attention because of its biological nature, or because its orientation is informative for the task, then responses should be significantly faster when congruent with its location and this effect should be larger as compared to when a geometrical shape is presented.

Methods

Participants

60 new right-handed undergraduate students (43 female, mean age = 21.6, SD = 1.98 years), selected as before, took part in this experiment for course credit.

Apparatus, stimuli and procedures

Apparatus, stimuli and procedures were the same as in the object-only condition of Experiment 1, except for what follows. Objects could be presented upward or inverted (i.e., vertical orientation) with a leftward- or rightward-oriented handle. For half of the participants, a human hand was presented opposite to the object handle (i.e., the hand was on the left of the object when the handle pointed rightward), while for the other half a filled square was presented opposite to the object handle (i.e., the square was on the left of the object when the handle pointed rightward). The distance from the centre of the hand/square to the centre of the object was of 5.72°. As in the previous experiments, participants were asked to respond according to the vertical orientation (upward or inverted) of the objects.

The experiment consisted of 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. An equal number of trials was provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and, for the opposite-hand condition only, type of hand (two males and two females).

Table 3 Mean RTs (and standard deviation) in ms in the two experimental conditions of Experiment 3 as a function of object vertical orientation (upright and inverted) and handle–response correspondence (corresponding and non-corresponding)

	Opposite hand		Opposite square	
	Upright	Inverted	Upright	Inverted
C	487 (82.3)	493 (82.4)	573 (88.1)	557 (67.2)
NC	481 (80.4)	481 (79.5)	558 (87.5)	549 (66.9)
Handle orientation effect	− 6	− 12	− 15	− 8

The handle orientation effect is computed as the difference in RTs between handle–response non-corresponding and corresponding trials

Results and discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (4.5% of the total trials) and incorrect responses (3.9% of the total trials) were excluded from the analyses. Correct RTs were entered into a repeated-measures ANOVA with handle–response correspondence and object vertical orientation as within-participant factors and condition (opposite-hand vs. opposite-square condition) as between-participant factor. The respective data are shown in Table 3.

There was a main effect of condition, $F(1,58) = 13.55$, $p < 0.001$, $\eta^2_p = 0.19$, with faster RTs in the opposite-hand condition (485 ms) than in the opposite-square condition (559 ms). The main effect of object vertical orientation did not reach significance ($p = 0.17$, $\eta^2_p = 0.03$), but it interacted with condition, $F(1,58) = 4.95$, $p < 0.05$, $\eta^2_p = 0.08$, with faster RTs for inverted than for upright objects in the opposite-square condition only.

The main effect of handle–response correspondence was significant, $F(1,58) = 17.14$, $p < 0.001$, $\eta^2_p = 0.23$, with faster RTs for non-corresponding (517 ms) than for corresponding (527 ms) trials. Hence, responses were faster when they were congruent with the position of the distractor presented along with the object. No difference between the square and the hand was evident, as indicated by the lack of the interaction between handle–response correspondence and condition, $F < 1$. The overall handle orientation effect was − 12 ms for the square and − 9 ms the hand. No other interaction reached significance (ps > 0.12).

Additional analyses

To assess whether the magnitude of the negative handle orientation effect found in the opposite-hand condition of Experiment 3 was as large as that of the positive effect found in grasped-object condition of Experiment 1, we submitted correct RTs to a repeated-measures ANOVA with handle–response correspondence as within-participant factor and condition (opposite-hand and grasped-object conditions) as between-participant factor. The analysis showed that the main effect of handle–response correspondence was significant, $F(1,58) = 18.11$, $p < 0.001$, $\eta^2_p = 0.23$, with corresponding responses being 10 ms faster than non-corresponding responses. The main effect of handle–response correspondence was significant also when the same analysis was performed to compare the opposite-hand condition of Experiment 3 and the approaching hand condition of Experiment 2, $F(1,58) = 16.73$, $p < 0.001$, $\eta^2_p = 0.23$.

These results indicate that the effect of a hand grasping an object's handle, or approaching it, is stronger that the effect of a hand located on the opposite side of the handle. Differently, the main effect of handle–response correspondence did not reach significance when the masked-handle condition of Experiment 1 was compared to the opposite-hand condition of Experiment 3, $F < 1$, indicating that the two effects annulled themselves.

To summarize, the results of this experiment indicate that the presence of a distractor close to the object captured attention and the resulting location coding produced a Simon-like effect. The negative handle orientation effect found in this experiment is as large as the positive effect found in the object-only condition of Experiment 1 but not as large as the positive effects found in the grasped-object condition of Experiment 1 and in Experiment 2 (approaching hand). This finding allows us to exclude that the increased effect observed in the grasped-object condition of Experiment 1 for upright objects and in Experiment 2 was due to participants using the hand orientation to perform the task. If this were the case, an effect comparable in size, although negative, should have been evident in this condition too. Hence, a hand displaying a pose congruent with the action of grasping an object's handle potentiates the same action in the observer. Differently, the presence of a hand that does not display a pose congruent with a grasping response toward the object captures attention and affects performance in the same way as a non-biological stimulus. These findings suggest that, even though salience contributes to performance, this contribution is separate from that deriving from the observation of a human hand performing an action compatible with interacting with the observed object.

General discussion

The main aim of the present work was twofold. First we examined whether in a SRC task handle orientation effects in response to pictures of graspable objects emerge even when these objects appear as already grasped. Second, we assessed whether the observed effects could be explained as due to spatial compatibility between the most salient part in the object/display and the hand of response rather than to action potentiation.

The results obtained when the object was presented as potentially graspable replicated those of previous studies (e.g., Iani et al., 2011; Tucker & Ellis, 1998) with faster responses when the object's handle was located on the same side of the responding hand. This result is usually interpreted as suggesting that object motor-related information automatically triggers congruent motor responses (e.g., Adamo & Ferber, 2009; Tucker & Ellis, 1998). Crucially, and in contrast to our predictions, this advantage was evident also when the object appeared as already grasped (29 ms) and when its handle was partially covered (17 ms). The finding of a greater effect when an upright object was already grasped seems to indicate that observing a human hand holding an object, especially when the latter is presented in its canonical orientation with a thumb-up posture (e.g. Rosenbaum et al., 1990), activates a process of motor simulation, even though the observer is prevented from potentially grasping the "occupied" object.

As indicated by the results of Experiment 2, this action potentiation seems to occur even when the observed hand is not grasping the object but it is located close to it and displays a pose congruent with grasping it. Differently from Experiment 1, in this experiment the handle–response correspondence effect did not vary as a function of object orientation. We reasoned that this difference could be due to the fact that in Experiment 2 the hand was displayed as approaching the object but the final state of the action (that for inverted objects would have corresponded to an uncomfortable hand orientation) was not depicted.

These results are in line with those of previous studies demonstrating that contextual action information present along with an object affects the time taken to identify the object (Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008), to identify how it is typically used (Yoon & Humphreys, 2005) and leads to correspondence effects on grasping responses (Girardi, Lindemann, & Bekkering, 2010); moreover, are consistent with the view that seeing a hand close to the object may activate the anticipation of the effects of the action thus producing the same effects evident when the end state of the action is observed (e.g., Hommel, 2009; Hommel et al., 2001).

To note, the results of the present study are apparently in contrast with those by Ellis et al. (2013) who found evidence of non-imitative influences of the actions performed by another agent seen both from the observer's point of view and from an allocentric perspective. In their study, participants viewed video clips of a left- or right-handed reach toward an object with a handle to the left or right and were asked to classify the object by making a left- or right-handed keypress. The authors found that observing a left-hand reach, in both viewpoints, was associated to faster responses with the right hand, while observing a right-hand reach was associated with faster responses with the same hand. To explain their findings they proposed that observing another agent grasping an object with the left hand could lead the observer to perceive the observed action as a "social" action (i.e., passing the object to the observer), hence potentiating a reach towards the part of the object that was not occupied. It should be noted that in their study the hand did not grasp the object but was shown before the actual grasp and could be located either at the handle or not-handle side of the object. Indeed, this position could lead participants to perceive the observed agent as displaying a social action hence potentiating a complementary action, while a grasping position, as used in our study, could be more likely perceived as an individual action, hence evoking an automatic simulation process mediated by the mirror neuron system (e.g., Gallese et al., 1996; Gallese et al., 2011).

More open to interpretations are the results obtained in the masked-handle condition since they could be explained both in terms of spatial coding of the stimulus' more salient part and in terms of perceptual completion of an "incomplete" object (e.g., Emmanouil & Ro, 2014; Grützner et al., 2010). Even though our results do not allow us to exclude one of these hypotheses, we believe the second explanation is consistent with the idea proposed by Vingerhoets, Vandamme, and Vercammen (2009) that, when seeing an object, our brain automatically tries to work out affordances based on both intrinsic and extrinsic object qualities provided by visual information. In the case of incomplete objects, information might also derive from amodal completion processes.

As already stated in the "Introduction", there is considerable increasing evidence supporting the explanation of handle orientation effects in terms of spatial compatibility (e.g., Cho & Proctor, 2010, 2011; Lien et al., 2013). To determine whether the observed effects could be due to perceptual saliency bringing to spatial coding, in Experiment 3 we presented the object along with a distractor (either a hand or a geometrical shape) positioned on the opposite side as the object's handle. Results indicated that the presence of a distractor close to the object captured attention and the resulting location coding produced a Simon-like effect. However, the analyses showed that the reversed effect found in this experiment was not as large as the positive effects found in the grasped-object condition of Experiment 1 and in Experiment 2 (approaching hand), hence allowing us to safely exclude that the increased effect observed in the grasped-object condition of Experiment 1 and in Experiment 2 could be explained solely in terms of spatial compatibility. Hence, a hand displaying a pose congruent with the action of grasping an object's handle potentiates the same action in the observer. Differently, the presence of a hand that does not display a pose congruent with a grasping response toward the object captures attention and affects performance in the same way as a non-biological stimulus (i.e., a geometrical shape). Overall, these findings suggest that, even though, salience contributes to performance, this contribution is separate from that deriving from the observation of a human hand performing an action compatible with interacting with the observed object.

We believe the results of the present study are in line with the increasing experimental evidence indicating that both motor affordance and spatial compatibility mechanisms may contribute to the observed handle orientation effects in tasks using the SRC paradigm (e.g., Iani et al., 2011; Kourtis & Vingerhoets, 2015, Pappas, 2014; Riggio et al. 2008; Saccone et al., 2016). A clear demonstration of this point derives from the results of a recent study by Saccone et al. (2016) in which participants were required to classify (Experiment 1), to discriminate the colour (Experiment 2) or the vertical orientation (Experiment 3) of objects with a left- or right-oriented handle presented in upper or lower locations by pressing two response buttons placed vertically one below the other. Different from previous studies using the SRC paradigm, in their experiment there was no explicit spatial relationship between the object's graspable part and the response, since they varied orthogonally. A vertical Simon effect, due to the correspondence between stimulus and response locations (upper or lower), was present in all three experiments. Only when the task required access to semantic knowledge about the object, a handle orientation effect, due to the congruency between object handle (left or right) and hand of response (left or right), was also evident. As suggested by Saccone and colleagues, these latter results clearly speak in favour of the affordance view and suggest that handle orientation effects emerging in tasks characterized by an explicit spatial relation between handle and response locations may result from the interplay between motor affordance and spatial compatibility mechanisms. We believe our study extents these findings in showing that contextual information may modulate which mechanism prevails over the other in determining actual performance: a hand that does not display a pose congruent with a grasping response toward an object captures attention thus leading to the emergence of spatial compatibility effects. Differently, a hand displaying a pose congruent with the action of grasping an object's handle is more likely to potentiate the same action in the observer.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest.

Ethical approval The manuscript does not report clinical studies or patient data. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study fulfilled the ethical standard procedure recommended by the Italian Association of Psychology (AIP). It was approved by the Department of Communication and Economics of the University of Modena and Reggio Emilia.

Informed consent Informed consent was obtained from all individual participants included in the study.

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