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Do my hands prime your hands?

The hand-to-response correspondence effect

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Abstract

Previous research has shown an effect of handle-response correspondence on key-press responses when participants judged the upright or inverted orientation of photographed one-handled graspable objects. In three experiments, we explored whether this effect still holds for symmetric graspable objects that are usually grasped by two hands (i.e. two-handled objects; e.g. shears). In Experiments 1 and 2, participants were required to perform a between-hand response in order to categorize cooking or amusement objects appearing as grasped from either an allocentric (Experiment 1) or an egocentric perspective (Experiment 2). In Experiment 3, they were required to perform a within-hand response to categorize the same stimuli appearing as grasped from an egocentric perspective. Across all three experiments, results showed that categorization was more difficult when the objects were displayed as grasped on the opposite side than the response rather than on the same side. We discuss the implications of these results for theories of action potentiation and spatial coding and suggest that different mechanisms may be recruited depending on the required action (i.e. response mode).

Keywords: action potentiation, affordance, handle-response effect, location coding, spatial compatibility, symmetric objects.

PsycINFO codes: 2323; 2330

Do my hands prime your hands? The hand-to-response correspondence effect

Over the millennia, human beings have become increasingly able to construct and manipulate tools until becoming able at manipulating the entire physical world (see Barsalou, 2016 for discussions). We moved from simply nailing wooden planks with the purpose of building a house to invent and use sophisticated artifacts such as personal computers. Understanding how we perceive and assess the possible motor acts afforded by objects in our environment is, therefore, of crucial importance.

Actions directed towards objects are dictated by their visual features (e.g. the orientation of a cup's handle) as well as by the actor's physical capabilities (e.g. having two hands available; see Gibson, 1979 for the original idea of "affordance"), and action goal (Rosenbaum, Marchak, Barnes, Vaughan, Slotta, & Jorgensen, 1990; see also Scerrati, D'Ascenzo, Lugli, Iani, Rubichi, & Nicoletti, forthcoming). Interestingly, research has shown that depicted objects, similarly to real objects, can pre-activate specific actions despite physical interaction with them does not take place. For example, Tucker & Ellis (1998) demonstrated that when participants were required to judge the upright or inverted position of depicted graspable objects, the orientation of the object's graspable part (i.e., the handle) affected performance with responses being faster when the position of the handle and the responding hand were spatially aligned compared to when they were not. This effect, known as the action potentiation effect (e.g., Tucker & Ellis, 1998) but also affordance (e.g., Riggio, Iani, Gherri, Benatti, Rubichi, & Nicoletti, 2008), handle-alignment (e.g., Bub, Masson, & Kumar, 2018), object-based (e.g., Lien, Jardin, & Proctor, 2013), and handle-response[1] correspondence effect (e.g., Iani, Ferraro, Maiorana, Gallese, & Rubichi, 2018) has been found across a variety of tasks, response modes and, more generally, experimental settings (e.g., Bub & Masson, 2010; Bub et al., 2018; Cho & Proctor, 2010, 2011; 2013; Iani, Baroni, Pellicano, & Nicoletti, 2010; Iani et al., 2018; Lien et al., 2013; Lien, Gray, Jardin, & Proctor, 2014; Matheson, White, & McMullen, 2014; Pappas, 2014;

[1] Throughout this manuscript we will be referring to the reduction of response times and error rates when handle and response correspond spatially as the handle-response correspondence effect.

Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; Pellicano et al., 2018; Proctor, Lien, & Thompson, 2017; Riggio et al., 2008; Saccone, Churches, & Nicholls, 2016; Song, Chen, & Proctor, 2014; Symes, Ellis, & Tucker, 2005; Tipper, Paul, & Hayes, 2006; Tucker & Ellis, 1998; Vainio, Ellis, & Tucker, 2007). Nevertheless, we still lack a shared *consensus* about its nature. On the one hand, the effect has been explained by assuming that perceiving action-relevant visual properties of an object (i.e. the orientation of a cup's handle) activates the actions most suited to interact with it (e.g., Iani et al., 2018; Pappas, 2014; Pellicano et al., 2010; Saccone et al., 2016; Symes et al., 2005; Tipper, et al., 2006; Tucker & Ellis, 1998). That is, the affordance for grasping by the left or right hand generates a left or right code which consists of the activation of limb-specific motor pattern.

In contrast to this *action potentiation hypothesis*, it has been maintained that correspondence effects of this sort do not involve specific activations in the motor system (e.g. Cho & Proctor, 2010, 2011, 2013; Proctor, Lien, & Thompson, 2017; see Proctor & Miles, 2014 for a review). Rather, according to advocates of the *location coding* (Cho & Proctor, 2010) and the *feature-asymmetry* accounts (Cho & Proctor, 2013; Song et al., 2014) the handle-response correspondence effect can be assimilated to other spatial compatibility effects. Spatial compatibility effects refer to the finding of better performances when stimuli and responses share the same location in space compared to when they do not (Fitts & Seeger, 1953). Spatial compatibility effects can be obtained even if people respond to nonspatial features of stimuli. For example, in the Simon effect (Simon, 1969; 1990) people are faster and more accurate to judge stimulus color, shape or pitch if stimulus position and response position correspond than if they do not correspond (for a detailed taxonomy of spatial compatibility effects see Kornblum & Lee, 1995; Kornblum & Stevens, 2002). According to the *location coding* (Cho & Proctor, 2010) and the *feature-asymmetry* accounts (Cho & Proctor, 2013; Song et al., 2014), the handle-response correspondence effect is an object-based Simon effect. As the Simon effect, which is brought about by the interaction between the irrelevant spatial location of the stimulus (left or right) and the relevant spatial location of the response (left or right; Simon, 1969; 1990; see also Scerrati, Lugli, Nicoletti, & Umiltà, 2017 for a recent investigation of the Simon effect), the handle-response correspondence effect would be due to the dimensional overlap (Kornblum, Hasbroucq, & Osman, 1990; Kornblum and Lee, 1995; Kornblum & Stevens, 2002) between stimuli and response spatial features. That is, the graspable parts of the objects, as they protrude on one side, create visual asymmetries within the stimulus display that become perceptually salient to the observer. The location of these salient portions generates a left or right spatial code that may or may not correspond with the spatial response code, thus producing the preconditions for the emergence of an object-based Simon effect (Cho & Proctor, 2011, 2013; Lien et al., 2013; Lien et al., 2014; Song et al., 2014; see Proctor & Miles, 2014 for a review).

The *location coding* and the *feature asymmetry* accounts gathered extensive support through the years. For instance, Cho and Proctor (2010) showed a handle-response correspondence effect during both color and orientation judgements of frying pan stimuli regardless of whether responses were operated with different hands (between-hand) or different fingers on the right hand (within-hand). Importantly, this finding speaks against the *action potentiation* hypothesis since when responding with different fingers on the right hand both responses are compatible with a right-hand grasp, thus no effect is expected. Furthermore, Song et al. (2014) showed that asymmetries on the body of torch stimuli produced a correspondence effect even when the handle was removed from the stimulus. More recently, Proctor et al. (2017) found a handle-response correspondence effect only when the base of the graspable object (rather than the entire object) was centered on the screen, and the handle was clearly located to the left or right side of the display. Pellicano et al. (2010) found a handle-response compatibility effect when horizontally-oriented torches depicted as active (switched on) on the monitor and centered on the basis of the picture width were judged as upright or inverted, and a reversed correspondence effect driven by the goal directed side of the torches when they were centered on the basis of the object body. In addition, Pellicano et al. (2019) found a handle-response correspondence effect in a joint go/no-go task (when there was an alternative response available to participants) but not in an individual unimanual go/no-go task (when there was no alternative response available to participants). These findings are counter to the *action potentiation hypothesis*, which predicts that motor response codes should be activated regardless of whether the stimulus is base-centered or object-centered and the task requires the emission of a single response (individual unimanual go/no-go task) or of two responses performed by different individuals (joint go/no-go task). Importantly, a recent meta-analysis conducted by Azaad, Laham & Shields (2019) on the handle-response correspondence effect obtained results mostly consistent with a location coding account.

However, it should be noted that there is also evidence suggesting that the handle-response correspondence effect can be dissociated from a standard Simon effect. For instance, Iani et al. (2011) showed that stimulus location and handle orientation produce separate effects that might or might not interact depending on the response action. Furthermore, Pappas (2014) showed that between-hands responses produced larger handle-response correspondence effects than within-hand responses when participants responded to photographs of objects. In a similar vein, Cho & Proctor (2011) reported smaller reversed handle-response correspondence effects for between- rather than within-hand response modes and Janyan and Slavcheva (2012) found a smaller handle-response correspondence effect when responses were emitted with the hands crossed rather than uncrossed. These results suggest that a competing correspondence effect due to action potentiation mechanisms may occur in the between- and uncrossed-hand condition. In addition, Saccone et al. (2016) found a handle-response correspondence effect with a kitchen/garage categorization task in the absence of explicit spatial compatibility between handle orientation and response position. More recently, Iani et al. (2018) reported faster responses to objects' vertical orientation when the object's handle was located on the same side as the responding hand, with a significantly larger effect when upright objects were shown as already grasped or when a hand was displayed close to the handle. Such finding has been interpreted as indicating that observing a human hand holding an object, or close to it, activates a process of motor simulation (see Borghi, Bonfiglioli, Lugli, Ricciardelli, Rubichi, & Nicoletti, 2006; see also Scerrati, Baroni, Borghi, Galatolo, Lugli, & Nicoletti, 2015; Scerrati, Lugli, Nicoletti, & Borghi, 2017 for recent investigations of the mechanism of simulation). That is, the hand may work as a motor prime that triggers a simulation of the possible actions afforded by the object, possibly with the contribution of the mirror neuron system (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Gallese, Gernsbacher, Heyes, Hickock, & Iacoboni, 2011).

Starting from this evidence, in the present study we assessed whether a correspondence effect emerges when objects that are usually grasped by two hands (i.e. two-handled objects; e.g. shears) are depicted as already grasped. We aimed at testing whether symmetric objects, displaying a graspable component on both sides of the object, can elicit a correspondence effect between a depicted grasping hand and the actual responding hand of the participant. We will refer to this effect as the hand-to-response correspondence effect. To this end, we compared centrally displayed photographs of two-handled objects in four conditions: in the Compatible Grasping condition the object was shown as grasped on the same side as the response; in the Incompatible Grasping condition the object was shown as grasped on the opposite side than the response; in the Object Alone condition a non-grasped object was shown; finally, in the Two-Handed Grasping condition the object was shown as grasped by both hands. The latter two conditions were included as control conditions (see below). We asked participants to respond either between- (Experiments 1 and 2) or within-hand (Experiment 3) to categorize objects depending on their habitual use (i.e., cooking or amusement purposes). Objects could appear as grasped from either an allocentric (Experiment 1) or an egocentric perspective (Experiments 2 and 3).

Of interest for the purposes of the present study is whether performance in the Compatible and Incompatible Grasping conditions differ, which would indicate the presence of a hand-to-response correspondence effect between the depicted grasping hand and the participant's responding hand. The introduction of the Object Alone condition was aimed at disentangling whether the expected hand-to-response correspondence effect reflects a facilitation (due to compatible response) or an interference (due to incompatible responses). In addition, we included the Two-Handed Grasping condition as a further control aimed at testing whether the presence of two hands might render the discrimination more difficult due to partial object occlusion.

Furthermore, according to the *location coding* (Cho & Proctor, 2010) and the *feature asymmetries* (Song et al., 2014) accounts, a facilitation should occur in the Compatible Grasping condition relative to the Object Alone condition due to the presence of relevant and salient visual features (i.e. the grasping hand) on the same side as the response in the former condition. In addition, the *location coding* account predicts that the magnitude of the hand-to-response correspondence effect is the same regardless of participants responding between- or within-hand (Cho & Proctor, 2010, 2011; Proctor et al., 2017) to stimuli in the egocentric perspective.

In contrast, according to the *action potentiation hypothesis*, the hand-to-response correspondence effect should be larger in the between- than within-hand condition. More important, the viewpoint in which the grasping hand is shown should affect the hand-to-response correspondence effect if a motor simulation occurs. That is, a smaller effect is expected when the hand is shown in the allocentric rather than the egocentric perspective. To illustrate, if people perceive the object as an “occupied” object on which someone else is acting (as they might do in the allocentric perspective), they could activate motor response codes to a lesser extent given that the object is potentially not available for their own action (see González-Perilli & Ellis, 2015 for the influence of phase kinematics on motor simulation; see also Cardellicchio, Sinigaglia, & Costantini, 2013; Ferri, Riggio, Gallese, Costantini, 2011 for similar hypotheses manipulating object distance rather than perspective).

Experiment 1

Experiment 1 was aimed at assessing whether photographed two-handled objects yield the activation of motor responses when they appear as grasped on one side. In this experiment, participants were required to categorize the objects based on their habitual use (i.e., cooking or amusement purposes) by pressing one of two lateralized keys with the index fingers from the two hands (between-hands responses). Objects could be shown alone or as already grasped by either one or two hands in the allocentric perspective. When only one grasping hand was shown, it could be grasping either the left or right end of the object. Based on the results of Iani et al. (2018) with one-handled objects, we expected responses to be faster when the grasping hand and the hand of response were spatially compatible (i.e., on the same side) as compared to when they were spatially incompatible (i.e., on opposite sides).

Method

Participants. We calculated the sample size required to achieve 95% power to detect a significant main effect of *Condition* (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) with the G*power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) software. With an effect size f = 0.25 (Cohen, 1988), the power calculation yielded a recommended sample size of at least 36 participants[2].

Thirty-six students from the University of Modena and Reggio Emilia (18 females; mean age: 21 years, SD: 2.5 years) participated in this experiment. Handedness was measured by the Edinburgh Handedness Inventory (Oldfield, 1971), which revealed that 24 participants were right-handed (laterality mean =0.75; SD =0.11), 11 participants were ambidextrous (laterality mean = 0.37; SD = 0.11) and 1 participant was left-handed (laterality = -0.71). All participants had 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 Education and Human Sciences of the University of Modena and Reggio Emilia. All participants gave their written informed consent to participate to the study.

Materials. Target stimuli were color photographs of eight two-handled objects, four mainly used in the kitchen for cooking purposes (colander, mezzaluna knife, sauce pot, rolling pin) and four mainly used during spare time for hobby/amusement purposes (beach sieve, joypad, shears, vase). Color photographs of objects were selected from a Google search of images. These objects subtended

[2] Note that the same sample size calculation was employed in the following experiments where the same main effect was analyzed.

a maximum of 11.6 degrees of visual angle horizontally and 8.5 degrees of visual angle vertically when viewed from a distance of 60 cm. Photographs of a male or female hand in the allocentric perspective (i.e. other people's viewpoint) were superimposed on object photographs. The original versions of these photographs were taken of the models' right hand, and a left-hand version of each was digitally generated by a mirror reversal by using Adobe Photoshop Elements 9. Given that certain hands could be superimposed on different objects, these hands were cropped and rotated as needed to make the grasp looking very natural. The hands were depicted in flesh color and subtended a maximum of 5.7 degrees of visual angle horizontally and 6.4 degrees of visual angle vertically when viewed from 60 cm. Female participants were shown objects grasped by female hand(s), whereas male participants were shown objects grasped by male hand(s). This arrangement was intended to ensure that participants could easily identify the model's hand(s) as their own hand(s). Four versions of each object's photograph were digitally generated: the object alone, the object grasped by both hands, the object grasped by a left hand, the object grasped by a right hand[3].

Procedure. Participants were tested individually in a dimly-lit room with the experimenter always present. They sat at a distance of 60 cm from the monitor and were asked to categorize each two-handled object as being mainly used in the kitchen or during spare time. Each object appeared as not grasped (Object Alone condition), as grasped by the two hands (Two-Handed Grasping condition), or as grasped by one hand only (i.e., left or right). When the object appeared as grasped by one hand only, the grasping hand was liable to be spatially compatible, that is, on the same side as the actual responding hand of the participant (Compatible Grasping condition) or incompatible, that is, on the opposite side than the actual responding hand of the participant (Incompatible Grasping condition). To note, when the object appeared as grasped on the right side, the depicted grasping hand was the agent's left hand, and when the object appeared as grasped on the left side, the depicted grasping hand

[3] The materials from this and the following experiments are available at: https://osf.io/cbkjg/?view_only=307a8eeb76864fa981526e407d8ede14

was the agent's right hand. Figure 1 shows a schematic representation of the four experimental conditions.

--INSERT FIG. 1 ABOUT HERE--

Each trial began with a fixation cross displayed at the center of a white background for 500 ms. Then the image of an object (either grasped or not grasped) was centrally displayed for a maximum of 2000 ms or until a response was given. Response key were the "-" and the "Z" keys on an Italian QWERTY keyboard. Response-key distance was about 17.5 cm from center to center. Half of the participants in each experimental condition responded by pressing the "-" key with their right index finger when a kitchen object appeared on the monitor, and the "Z" key with their left index finger when a spare time object appeared on the monitor. The other half was assigned to the opposite mapping. After a response was given, a blank screen was displayed for 600 ms. Instructions emphasized both speed and accuracy of responses.

The experiment consisted of 32 practice trials and 3 experimental blocks of 128 trials each, for a total of 416 trials per participant. Trials were randomly presented and blocks were separated by a self-paced interval. An equal number of trials (96) was shown in each condition. Each object appeared in each condition 12 times. Feedback was provided during practice.

Results and Discussion

Practice trials, omissions (0.07%) and response times faster or slower than 2 standard deviations from the participant's mean (4.4%) were excluded from the analyses. Mean Reaction Times (RTs) of correct responses (proper categorization through proper button press) and arcsin-transformed Error Rates (ERs: improper categorization through improper button press; 3.4 % of experimental trials) were entered into two separate repeated-measures ANOVAs with *Condition* (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) as the within-participant factor. When sphericity was violated, the Huynh-Feldt correction was applied, although the original degrees of freedom are reported. Descriptive statistics are shown in Figures 4 and 5.

The main effect of *Condition* was significant for RTs, $F(3,105) = 16.99$, $MS_e = 105.78$, $p < .001$, $\eta_p^2 = .327$, while it did not reach statistical significance for ERs, $p = .154$. Holm-Bonferroni-corrected planned comparisons were used to compare the four experimental conditions for RTs. RTs were significantly slower in the Incompatible Grasping condition as compared to both the Compatible Grasping condition, $t(35) = 5.02$, $p < .001$, and the Object Alone condition, $t(35) = 4.57$, $p < .001$. Furthermore, RTs were slower in the Two-Handed Grasping condition as compared to both the Compatible Grasping condition, $t(35) = 5.55$, $p < .001$ and the Object Alone condition, $t(35) = 3.78$, $p = .001$. No other contrast turned out to be significant, $t_s < 1.38$.

In sum, responses were slower when the object was shown as grasped on the opposite side than the response as compared to when it was shown either as grasped on the same side as the response or as not grasped at all. In line with the *action potentiation* hypothesis and with the results of previous studies (e.g., Iani et al., 2018), this finding could be interpreted as indicating that observing a hand grasping one end of a two-handled object activates the same action in the observer, slowing down the incompatible responses. Alternatively, it could be argued that when the object was depicted as grasped by one hand, one side of the display was more spatially salient than the other, this leading to the creation of a spatial code that could overlap with the response yielding to the emergence of a hand-to-response Simon effect. However, it should be noted that there was no difference between the Compatible Grasping condition and the Object Alone condition, indicating that our finding of a correspondence effect between the object's grasped side and the response side is at least not entirely explained by a left-right asymmetry of visual features (i.e. *feature-asymmetry account*). Indeed, in the Compatible Grasping condition visual features (i.e. the grasping hand) were more relevant and salient on the same side as the response, an aspect that according to the *feature-asymmetry* account should have ensured faster and more accurate responses than in the Object Alone condition. No such facilitation was, however, found, despite the fact that in the Object Alone condition both sides were equal in terms of visual salience due to the symmetry of the object. Given that neither the Compatible nor the Incompatible Grasping conditions differed from both control conditions (i.e., Object Alone and Two-Handed Grasping conditions), no assumption can be made as to whether the observed effect reflects a facilitation or an interference. The finding of slower responses in the Two-Handed Grasping condition compared to the Object Alone condition suggests that the two control conditions are not equivalent. It could be argued that since the hands partially occluded the object, they might have rendered the discrimination more difficult. Alternatively, the hands may have distracted participants from the classification task. It should, however, be noted that the Two-Handed Grasping condition did not differ from the Incompatible Grasping condition in which only one side of the object was occluded. This finding may instead suggest that any condition showing at least an incompatible hand slowed down RTs.

The lack of differences between conditions for Error Rates echoes previous studies (e.g. Saccone et al. 2016, Experiment 1) in which handle-response correspondence effects were found for RTs but not for ERs. As argued by Saccone et al. (2016), such a result might be due to RTs being a more sensitive measure of cognitive processes than ERs.

Taken together these results do not argue in favor of either one of the two accounts. For this reason, we addressed the pattern of results obtained in Experiment 1 in a follow-up experiment. It should be considered that in Experiment 1 the hands were shown from an allocentric perspective (i.e. other people's viewpoint). Although we showed male and female hands to male and female participants, respectively, our manipulation might have been insufficient to ensure participants' identification with the model. In other words, an enhancement of action potentiation due to motor neuron activation might occur to a lesser extent if objects are perceived as undergoing others' actions. A way to test this possibility is to show the hands from an egocentric perspective. Egocentric hands could encourage participants to consider the object as available for their own actions. Experiment 2 was designed to test this hypothesis.

Experiment 2

Experiment 1 showed a hand-to-response correspondence effect, that is, categorization was slower when two-handled objects were shown as grasped by a hand on the opposite side than the response rather than on the same side as the response or on no side. It is plausible to assume that the perspective in which the grasping hands were shown affected the emergence of the hand-to-response correspondence effect. Indeed, it is likely that seeing the image of a pair of shears grasped by a hand that is perceived as belonging to another person (i.e., allocentric perspective) might induce people to activate motor codes for responding to a small extent. Differently, seeing the same object grasped by a hand perceivable as one's own hand might lead to a more pronounced activation of motor response codes. In other words, if people perceive the object as an "occupied" object on which someone else is acting (as they might do in the allocentric perspective), they could activate motor response codes to a lesser extent given that the object is not potentially available for their own action. Therefore, Experiment 2 was aimed at investigating whether the effect of hand-to-response correspondence found in Experiment 1 is influenced by the viewpoint in which the grasping hand is shown. To this end, we presented participants with photographs of objects that were grasped by male and female hands shown from an egocentric perspective. If activation in the motor system is stronger when the depicted grasping hand is perceived as our own (Borghi et al., 2006; Gallese et al., 1996; 2011), we expect to find a larger hand-to-response correspondence effect in Experiment 2 compared to Experiment 1.

Method

Participants. Thirty-eight new participants (20 females; mean age: 21 years, SD: 4 years) took part in this experiment voluntarily. They were students at the University of Modena and Reggio Emilia. Handedness was measured by the Edinburgh Handedness Inventory (Oldfield, 1971), which revealed that 31 participants were right-handed (laterality mean = 0.73; SD = 0.17) while 7 participants were ambidextrous (laterality mean = 0.27; SD = 0.33). All participants had normal or corrected to normal vision and were naïve as to the purpose of the experiment. All gave their written informed consent to participate.

Materials. Stimuli were identical as those used in Experiment 1 except that photographs of a male or female hand in the egocentric perspective (i.e. one's own viewpoint) were superimposed on object photographs (see Figure 2 for details). To make these stimuli as plausible as possible a slightly wider amount of the arm was in view in the egocentric perspective. The original versions of these photographs were taken of the models' right hand, and a left-hand version of each was digitally generated by a mirror reversal by using Adobe Photoshop Elements 9. The hands were depicted in flesh color and subtended a maximum of 8.3 degrees of visual angle horizontally and 10.9 degrees of visual angle vertically when viewed from a distance of 60 cm.

Procedure. The procedure was identical to that of Experiment 1, the only difference being that when the object appeared as grasped on the right side, the depicted grasping hand was the agent's right hand, and when the object appeared as grasped on the left side, the depicted grasping hand was the agent's left hand.

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Results[4] and Discussion

Practice trials and omissions (0.17%) were excluded from the analyses. Outliers RTs were discarded based on the same criteria as in Experiment 1 (4.7%). Mean RTs of correct responses and arcsin-transformed ERs (4.4 % of experimental trials) were entered into two separate repeated-measures ANOVAs with *Condition* (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) as the within-participant factor. When sphericity was violated, the Huynh-Feldt correction was applied, although the original degrees of freedom are reported. Descriptive statistics are shown in Figures 4 and 5.

Both analyses showed a main effect of *Condition*, $F(3,111) = 21.91$, $MS_e = 248.02$ $p < .001$, $\eta_p^2 =.372$ and $F(3,111) = 10.65$, $MS_e = .005$, $p < .001$, $\eta_p^2 =.223$ for RTs and ERs, respectively. Holm-

[4] Data from Experiments 2 and 3 have been published in Italian as a brief report: Scerrati, Iani, Lugli, & Rubichi (in press). C'è un effetto di potenziamento dell'azione con oggetti bimanuali? *Giornale Italiano di Psicologia.*

Bonferroni-corrected planned comparisons were used to compare the four experimental conditions for both dependent variables (RTs and ERs).

Responses in the Incompatible Grasping condition were significantly slower than responses in the Compatible Grasping, $t(37) = 6.59$, $p < .001$, Object Alone, $t(37) = 6.09$, $p < .001$, and Two-Handed Grasping, $t(37) = 3.26$, $p = .002$ conditions. Furthermore, responses in the Two-Handed Grasping condition were significantly slower than responses in the Compatible Grasping, $t(37) = 5.14$, $p < .001$, and Object Alone, $t(37) = 2.68$, $p = .01$ conditions. No other contrast turned out to be significant, $t = 1.61$.

A very similar pattern of results was found for ERs that were significantly higher in the Incompatible Grasping condition compared to the Compatible Grasping, $t(37) = 4.59$, $p < .001$, Object Alone, $t(37) = 3.19$, $p =.003$, and Two-Handed Grasping, $t(37) = 4.14$, $p < .001$ conditions. No other contrast turned out to be significant, $t_s < 1.81$.

In sum, responses were slower and less accurate when the object was shown as grasped on the opposite side than the response as compared to when it was shown as grasped on the same side, on both sides or as not grasped at all. Crucially, neither RTs nor ERs differed between the Compatible Grasping and the Object Alone conditions, replicating results from Experiment 1 and further suggesting that the hand-to-response correspondence effect is not entirely attributable to a left-right asymmetry of visual features of the stimuli. Contrary to Experiment 1, in Experiment 2 performance was worse in the Incompatible Grasping condition than in both control conditions (i.e., Object Alone and Two-Handed Grasping conditions). This finding, along with the lack of a difference between the Compatible Grasping and the Object Alone conditions, seems to suggest that the hand-to-response correspondence effect may reflect an interference of incompatible responses rather than a facilitation of compatible responses. Furthermore, we replicated the finding of slower performances in the Two-Handed Grasping condition compared to the Object Alone condition, which fosters our suggestion that the presence of hands makes it more difficult to ignore the irrelevant response compared to when two handles are shown as not grasped. The finding that the Incompatible Grasping condition was slower than the Two-Handed Grasping condition allow us to exclude that the presence of the two hands deteriorates performance due to partial object occlusion.

It is worth noting that Tucker & Ellis (1998), and more recently Proctor et al. (2017), pointed out that the conclusion that the handle-response correspondence effect is due to a grasping affordance hinges on the effect not only being present for between-hand responses but also absent (or at least significantly smaller) for within-hand responses. Given these considerations, in Experiment 3 we replaced the between-hand response mode with the within-hand response mode.

Experiment 3

Experiment 3 sought to further explore the conditions necessary to observe the hand-to-response correspondence effect. To this end, the response mode was manipulated by requiring participants to respond with the index and middle fingers of each hand in turn (i.e. within-hand responses) rather than with the right and left index fingers from each hand (i.e. between-hand responses; Experiments 1 and 2). Indeed, if the effect is the consequence of the activation of a response based on spatial relevant visual features (i.e., more visual information on one side of the object than the other), as argued by supporters of the *location coding* and *feature asymmetries* accounts, then using a single effector to implement responses should not hinder the occurrence of the effect. Conversely, if the effect reflects an enhancement of action potentiation due to motor neuron activation, then using a single effector to implement responses should hinder the occurrence of the effect or, at least, should produce a significantly smaller and/or qualitatively different (in terms of time course) hand-to-response correspondence effect since response hand itself is relevant to the activation of motor codes.

Method

Participants. Forty new students from the University of Modena and Reggio Emilia (20 females; mean age: 21 years, SD: 2.6 years) participated in the Experiment voluntarily. Handedness was measured by the Edinburgh Handedness Inventory (Oldfield, 1971), which revealed that there were 29 right-handed participants (laterality mean = 0.73; SD = 0.15) and 11 ambidextrous participants (laterality mean = 0.31; SD = 0.24). All participants had normal or corrected to normal vision and were naïve as to the purpose of the experiment. Written informed consent was obtained from all individuals included in the study.

Materials. Stimuli were identical as those from Experiment 2.

Procedure. The procedure was identical to that of the previous experiments except for what follows. First, participants were required to respond with the index and middle fingers of each hand in turn[5] (i.e. within-hand responses) rather than with the right and left index fingers from each hand (i.e. between-hand responses; Experiment 1 and 2). Second, there were 4 blocks of trials to this experiment for a total of 512 experimental trials, which were preceded by two practice blocks of 32 trials each (one for each responding hand). Adding an extra block to this Experiment was done in order to counterbalance participants' responding hand. Thus, there were 2 blocks for each responding hand. Half of the participants started responding with the right hand to the first two blocks of trials and responded with the left hand to the last two blocks, whereas the other half of participants started responding with the left hand to the first two blocks of trials and responded with the right hand to the last two blocks.

Response keys were the "J" and "L" keys on an Italian QWERTY keyboard (about 4 cm center to center). They were chosen to be comfortable enough to provide a response in the within-hand response mode. Half of the participants in each experimental condition responded by pressing the "J" key on the keyboard with their right index finger when a kitchen object appeared on the monitor, and the "L" key on the keyboard with their left index finger when a spare time object appeared on the monitor. The other half was assigned to the opposite mapping. Correspondence concerned position of the depicted grasping hand (whether left or right) and position of the actual responding finger (whether on the left or on the right; see Figure 3 for details).

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[5] Participants were invited to keep their non-responding hand on the desk throughout the experiment.

Results and Discussion

Practice trials and omissions (0.3%) were excluded from the analyses. Outliers RTs were discarded based on the same criteria as in Experiments 1 and 2 (4.8% trials). Mean RTs of correct responses and arcsin-transformed ERs (4.1% of experimental trials) were entered into two separate repeated-measures ANOVAs with *Condition* (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) as the within-participant factor. When sphericity was violated, the Huynh-Feldt correction was applied, although the original degrees of freedom are reported. Descriptive statistics are shown in Figures 4 and 5.

The analyses showed a main effect of *Condition* for both RTs, $F(3,117) = 23.95$, $MS_e = 164.11$, $p < .001$, $\eta_p^2 = .380$, and ERs, $F(3,117) = 5.75$, $MS_e = .002$, $p = .001$, $\eta_p^2 = .128$[6]. Holm-Bonferroni-corrected planned comparisons were used to compare the four experimental conditions for both dependent variables (RTs and ERs).

Responses in the Incompatible Grasping condition were significantly slower than responses in the Compatible Grasping, $t(39) = 6.66$, $p < .001$, Object Alone, $t(39) = 6.17$, $p < .001$, and Two-Handed Grasping, $t(39) = 2.71$, $p = .01$ conditions. In addition, responses in the Two-Handed Grasping condition were significantly slower than responses in the Compatible Grasping, $t(39) = 4.65$, $p < .001$ and Object Alone, $t(39) = 4.67$, $p = .001$, conditions. No other contrast turned out to be significant, $t = .523$.

ERs were significantly higher in the Incompatible Grasping than in the Compatible Grasping condition, $t(39) = 3.43$, $p = .001$. Interestingly, ERs were significantly lower in the Compatible

[6] Given the high percentage of ambidextrous participants in Experiments 1 (31%), 2 (18%), and 3 (28%) we ran a mixed ANOVA on RTs with *Condition* (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) as the within participant factor and *Handedness* (right-handed, left-handed, ambidextrous) and *Experiment* (1, 2, 3) as the between participants factors. The critical three-way interaction between *Condition*, *Handedness*, and *Experiment* was not significant ($p = .542$), indicating that handedness of participants did not affect RT results from our Experiments. A mixed ANOVA was also run on arcsin-transformed error rates with the same factors as for RT. Again, the critical three-way interaction between *Condition*, *Handedness*, and *Experiment* was not significant ($p = .975$), confirming that handedness of participants did not affect results from our Experiments.

Grasping condition than in the Object Alone condition, $t(39) = 3.12$, $p = .003$. No other contrast turned out to be significant, $t_s < 2.43$.

In sum, an object grasped on the opposite side than the response by an egocentric hand slowed down within-hand responses and made them less accurate than an object grasped on a) the same side as the response; b) both sides; c) no side. This finding is in line with previous research demonstrating handle-response correspondence effects for within-hand responses with one-handled objects (Cho & Proctor, 2010, 2011; Pappas, 2014; Proctor et al., 2017).

The finding of slower RTs in the Incompatible Grasping condition compared to both control conditions (i.e., Object Alone and Two-Handed Grasping conditions) echoes results from Experiment 2 and further supports the suggestion that the hand-to-response correspondence effect reflects an interference of incompatible responses rather than a facilitation of compatible responses. In addition, we replicated the finding of worst performances in the Two-Handed Grasping condition compared to the Object Alone condition, which we obtained in both previous experiments. That is, viewing two hands grasping a symmetric two-handled object makes it more difficult to ignore the irrelevant response compared to viewing a symmetric two-handled object *per se*.

Importantly, RTs did not differ between the Compatible Grasping condition and the Object Alone condition, confirming the pattern found in our previous experiments. Conversely, error rates in the Compatible Grasping condition were significantly smaller than error rates in the Object Alone condition.

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Additional Analyses

Bayesian analysis. We performed a Bayesian analysis[7] aimed at testing whether the absence of a significant difference between the Compatible Grasping and Object Alone conditions in all three

[7] We thank an anonymous reviewer for suggesting this analysis.

experiments can be taken as evidence in favor of the null hypothesis. Indeed, based on the procedure of null hypothesis significance testing (NHST) the null hypothesis can never be accepted, one just fails to reject it. To further examine whether the Compatible Grasping and Object Alone conditions did not actually differ, we collated data from the three experiments and computed a Bayes factor (Wagenmakers, 2007). This analysis was performed using R (R Core Team, 2016) with the 'BayesFactor' library, using the default JZS prior (Rouder, Speckman, Sun, Morey, Iverson, 2009) and was aimed at comparing the plausibility of the null and the alternative hypotheses (H_0, H_1, respectively) relative to the absence of a significant difference between the Compatible Grasping and Object Alone conditions. We found that the Bayes factor (BF_{01}), expressing the probability of the data given H_0 (i.e., no difference) relative to H_1 (i.e., difference), was $BF_{01} = 3.9$ (Wagenmakers, 2007; see also Raftery, 1995). That is, H_0 is between three and four times more likely than H_1. This result further suggests that responses in the Compatible Grasping condition were not faster than responses in the Object Alone condition[8].

Combined analysis. We ran a between-experiments analysis on RTs aimed at comparing the observed effects. RTs were submitted to an ANOVA with *Correspondence* (compatible grasping vs. incompatible grasping) as the within-participant factor and *Experiment* (1, 2, 3) as the between-participants factor. The analysis showed a main effect of *Correspondence*, $F(1,111) = 109.75$, $MS_e = 217.69$, $p < .001$, $\eta_p^2 = .497$, a main effect of *Experiment*, $F(2,111) = 8.89$, $MS_e = 9474.52$, $p < .001$, $\eta_p^2 = .138$, and a significant interaction between *Correspondence* and *Experiment*, $F(2,111) = 3.61$, $MS_e = 787.49$, $p = .030$, $\eta_p^2 = .061$.

Given the significant main effect of Experiment, we conducted three independent t-test aimed at comparing mean RTs across experiments. We found that categorization was slower when responding

[8] For the sake of completeness, a Bayes Factor aimed at examining the plausibility of the null and the alternative hypotheses (H_0, H_1, respectively) concerning the absence of a significant difference between the Compatible Grasping and Object Alone conditions was also computed for each experiment separately. This gave $BF_{01} = 2.7$ in Experiment 1, $BF_{01} = 1.8$ in Experiment 2, and $BF_{01} = 5.1$ in Experiment 3. Thus, across Experiments, H_0 was approximately from two to five times more likely than H_1. Hence, although to different extents, also the separate Bayesian analyses provided (some) support for the null hypothesis.

within- compared to between-hands. Specifically, overall RTs were slower in Experiment 3 (M = 603 ms, SD = 80.65) than in Experiment 1 (M = 539 ms, SD = 50.52), $t(74) = 4.10$, $p < .001$, $d = 0.95$, and 2 (M = 557 ms, SD = 70.27), $t(76) = 2.68$, $p = .009$, $d = 0.60$. The finding of overall slower RTs in Experiment 3 compared to both Experiments 1 and 2 could be due to within-hand responses being a more difficult response mode to implement than between-hands responses.

To clarify the significant interaction between *Correspondence* and *Experiment*, we further conducted three independent t-test aimed at comparing the magnitude of the hand-to-response correspondence effect across the three experiments (see Figure 6 for details). The hand-to-response correspondence effect was computed by subtracting mean RT for compatible grasping trials from that for the incompatible grasping trials. The hand-to-response correspondence effect was significantly smaller in Experiment 1 (M = 15 ms, SD = 17.64) than in Experiment 2 (M = 27 ms, SD = 25.76), $t(72) = 2.49$, $p =.015$, $d = 0.53$. The effect did not significantly differ in magnitude between Experiment 2 (27 ms, SD = 25.76) and Experiment 3 (19 ms, SD =18.16), $t(76) = 1.68$, $p =.097$, $d = 0.35$, and between Experiment 1 (M = 15 ms, SD = 17.64) and Experiment 3 (19 ms, SD =18.16), $t(74) = 1.05$, $p =.295$, $d = 0.22$.

The finding of a smaller hand-to-response correspondence effect in Experiment 1 than in Experiment 2 provides somewhat preliminary evidence for a role of the perspective or viewpoint (egocentric vs. allocentric) in the occurrence of correspondence effects with grasped symmetric two-handled objects and speaks in favour of the *action potentiation* hypothesis. Participants were more prone to activate a motor response code for their own responding hand when the depicted grasping hand was in the egocentric perspective likely because this perspective allowed them perceiving the depicted hand(s) as their own, and the object as available for their own action. Similar results have been obtained when manipulating object distance from the participant (e.g., Cardellicchio et al., 2013; Ferri et al., 2011).

It is worth noting that the amount of the arm in view slightly differed between Experiment 1 (allocentric perspective) and Experiments 2 and 3 (egocentric experience). It is, however, unlikely that this difference influenced the magnitude of the hand-to-response correspondence effect between Experiments 1 and 2 for at least two reasons. First, stimuli were the same in both Experiments 2 and 3, however, a difference in terms of the effect only emerged between Experiments 1 and 2. If it was the slightly greater amount of the arm in view that produced a larger hand-to-response correspondence effect in Experiment 2 than in Experiment 1 then the same pattern should have occurred when comparing Experiments 1 and 3. Indeed, in Experiment 3 we used the same stimuli as in Experiment 2. Second, the amount of the arm in view had no effect on overall RTs when comparing Experiments 1 and 2, $t(72) = 1.26$, $p = .210$, $d = 0.29$.

Importantly, although the hand-to-response correspondence effect found in Experiments 3 was numerically smaller than that found in Experiment 2 they did not statistically differ as one would have expected if action potentiation mechanisms were at work (for similar results see Proctor et al., 2017, Experiment 1). This result speaks in favour of the *location coding* account. Indeed, according to this account using a single effector to implement responses does not prevent the correspondence effect from arising.

In order to shed further light on this mixed pattern of results we performed distributional analyses on RTs from all three experiments.

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RT distribution analyses. Previous studies consistently found long-lasting and gradually developing handle-response correspondence effects with one-handled objects (Cho & Proctor, 2010; Phillips & Ward, 2002; Proctor et al., 2017; Riggio et al., 2008; Roberts & Humphreys, 2010; Saccone et al., 2016). Such a time course has been interpreted as being counter to functionally automatic processes such as motoric activation (Proctor & Miles, 2014). We examined RT distributions from all three experiments (see Figure 7 for details). We expected to find potential qualitative differences between the time course of the correspondence effects in Experiments 1 and 2 compared to Experiment 3 if action potentiation mechanisms were at work.

To assess the time course of the observed correspondence effect we applied the Vincentizing procedure (Ratcliff, 1979). Rank ordered RTs for Compatible and Incompatible grasping trials were divided into four quartiles (bins) and the mean RT for each quartile was calculated. A repeated-measures ANOVA was run with *Bin* (1-4) and *Correspondence* (compatible grasping vs. incompatible grasping) as within-subject factors for all three experiments. Note that, considering the way the data were grouped, the *Bin* main effect was necessarily significant in all analyses. Therefore, it is not reported and discussed here or later on.

As for Experiment 1, the analysis showed only a main effect of *Correspondence*, $F(1,35) = 24.77$, $MS_e = 635.90$, $p < .001$, $\eta_p^2 =.415$. The two-way interaction between *Bin* and *Correspondence* did not reach significance, $F = 1.4$, $p = .245$, indicating that the correspondence effect did not vary across bins. As for Experiment 2, the analysis showed a main effect of *Correspondence*, $F(1,37) = 43.49$, $MS_e = 1315.44$, $p < .001$, $\eta_p^2 =.540$. As in Experiment 1, the two-way interaction between *Bin* and *Correspondence* did not reach significance, $F < 1$, $p = .555$ indicating that the correspondence effect did not vary across bins. Finally, as for Experiment 3, the analysis showed a main effect of *Correspondence*, $F(1,39) = 44.55$, $MS_e = 649.55$, $p < .001$, $\eta_p^2 =.533$, and a significant two-way interaction between *Bin* and *Correspondence*, $F(3,117) = 3.74$, $MS_e = 298.68$, $p = .033$, $\eta_p^2 =.088$. Paired sample *t*-tests showed that the correspondence effect was significant at all bins, $t_s(39) > 3.44$, $p_s < .001$. Helmert contrasts showed that its size increased significantly from bin 1 to bin 2 (11 and 17 ms), $F\ (1,39) = 9.67$, $p = .003$, $\eta_p^2 > .199$ and remained stable from bin 2 to bin 4 (23 and 24 ms), $F_s\ (1,39) < 3.42$, $p_s >.072$, $\eta_p{}^2{}_s < .081$ (see Figure 7)[9].

Taken together, these findings seem to suggest a qualitative difference (in terms of time course) between the hand-to-response correspondence effect observed in Experiment 3 and those observed in

[9] In order to compare the time course of the hand-to-response correspondence effect between Experiments 2 and 3, where the hands were shown in the same perspective (i.e., egocentric), we conducted a repeated measure ANOVA with the magnitude of the effect as the dependent variable, *Bin* (1-4) as the within-subject factor and *Experiment* (2, 3) as the between-subjects factor. The hand-to-response correspondence effect was computed by subtracting mean RT for compatible grasping trials from that for the incompatible grasping trials. Results showed a marginally significant interaction between *Bin* and *Experiment*, $F(3,228) = 2.45$, $MS_e = 867.54$, $p = .064$, $\eta_p^2 > .031$. Further independent t-tests revealed a significant difference concerning the first two bins across Experiments, with larger effects in Experiment 2 (bin1: 27 ms; bin2: 29 ms) than Experiment 3 (bin1: 11 ms; bin2: 17 ms), $t_s(76) < 3.28$, $p_s > .002$.

Experiments 1 and 2. This result might underlie the presence of different mechanisms in the occurrence of the hand-to-response correspondence effect. We discuss this further in the General Discussion.

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General Discussion

The present study demonstrated that grasped symmetric two-handled objects can elicit a correspondence effect between the depicted grasping hand and the actual responding hand of the participant. This hand-to-response correspondence effect reflected an interference of incompatible responses. More specifically, across all three experiments, the presence of a hand grasping one object's end affected performance with slower responses and, in Experiments 2 and 3, also higher percentages of errors when the depicted hand and the response were spatially incompatible (i.e., on different sides) as compared to when they were spatially compatible (i.e., on the same side).

Interestingly, this hand-to-response correspondence effect varied in size and robustness as a function of the perspective in which the grasping hand was shown. More precisely, when the grasping hand was shown from an allocentric perspective (Experiment 1), a significant 15-ms correspondence effect emerged for RTs. The effect was not significant for ERs (1.3 %). Differently, when the grasping hand was shown from an egocentric perspective (Experiment 2) a significantly larger hand-to-response correspondence effect emerged for RTs (27 ms) and was significant also for ERs (3.3%). These results are in line with previous studies showing that observing a human hand holding an object activates a process of motor simulation (see Borghi et al., 2006) probably mediated by the mirror neuron system (e.g., Gallese et al., 1996; 2011). In other words, the hand acts as a motor prime, which triggers a simulation of the possible actions afforded by the object (González-Perilli & Ellis, 2015). As a consequence, an enhancement of action potentiation due to motor neuron activation occurs. The lack of a hand-to-response correspondence effect for ERs together with a smaller effect for RTs when the objects appeared as grasped by another person's hand is consistent with the idea that observing an object that appears as already grasped by another agent may lead to weaker activations of the motor system as compared to when the grasping hand is perceived as belonging to the self. The finding of larger hand-to-response correspondence effects when the grasping hand is shown in the egocentric rather than allocentric perspective echoes previous studies showing that objects closer to the observer elicit motor activation to a greater extent than objects which are out of reach (e.g., Cardellicchio et al., 2013; Ferri et al., 2011): As close objects, available ones can trigger actions involving them more easily.

Importantly, however, the hand-to-response correspondence effect emerged for both RTs (19 ms) and ERs (1.7%) in Experiment 3 in which responses were made with the middle and index fingers of the same hand (within-hand responses) and did not statistically differ from the effect observed in Experiment 2. Such a result is evidence against the *action potentiation* account since in Experiment 3 one single hand implemented both responses. Hence, the same hand was simultaneously afforded by object stimuli in the Compatible Grasping condition, and “unafforded” by object stimuli in the Incompatible Grasping condition. As noted by Tucker & Ellis (1999), in such a situation none (or a significantly smaller) correspondence effect should occur if action potentiation mechanisms were at work. We found that although within-hand responses from Experiment 3 yielded a numerically smaller effect than between-hand responses from Experiment 2, the two effects did not statistically differ (for similar results with one-handled objects see Cho & Proctor, 2010, 2011; Proctor et al. 2017, Experiment 1). Given the relevance of this result, one might be tempted to conclude that the correspondence effects observed in our experiments are more likely to be due to abstract spatial codes, as claimed by the *location coding* and the *feature asymmetries* accounts (e.g. Cho & Proctor, 2010, 2011; Proctor et al., 2017; see Proctor & Miles, 2014 for reviews). That is, rather than action potentiation mechanisms, it was the overlap between the stimulus’ spatial properties and the response’s locations that yielded the observed effects.

It is, however, worth noting that the *location coding* and the *feature asymmetries* accounts cannot either completely explain our data. Importantly, the presence of salient visual features (i.e. the grasping hand) appearing on the same side as the response's side (i.e. Compatible Grasping condition) did not produce a better performance than the lack of thereof (i.e. Object Alone condition). Indeed, according to the *feature-asymmetry* account (Cho & Proctor, 2013; Song et al., 2014) developed by supporters of the *location coding* account, greater left-right asymmetry on the visual display leads to significant correspondence effects. In fact, no such facilitation was found in the present experiments, as witnessed by the absence of any significant difference between the Compatible Grasping and the Object Alone conditions in both Experiments 1 and 2 for either dependent variable (RTs, ERs), and in Experiment 3 for RTs. Therefore, our finding of a hand-to-response correspondence effect with symmetric two-handled objects when they appear as grasped on one side cannot be entirely attributed to a left-right asymmetry of stimuli.

It is also worth emphasizing that the results of the RTs distribution analysis did not highlight the usual increasing pattern in neither Experiment 1, nor 2. Previous evidence was consistent in reporting a slow development of the handle-response correspondence effect with one-handled objects (Cho & Proctor, 2010; Phillips & Ward, 2002; Proctor et al., 2017; Riggio et al., 2008; Roberts & Humphreys, 2010; Saccone et al., 2016; though see Bub, Masson, & Kumar, 2017 for handle-response correspondence effects that did not increase with longer response times). The slowly increasing time-course of the handle-response correspondence effect has been interpreted as being counter to functionally automatic processes such as motoric activation (Proctor & Miles, 2014). We only detected a long-lasting and gradually developing hand-to-response correspondence effect in Experiment 3, where participants responded with the index and middle finger of each hand in turn. The finding that only Experiment 3 showed a significantly increasing hand-to-response correspondence effect might suggest that different sources of the effect are involved depending on the required response mode. That is, the two mechanisms (spatial coding and action potentiation) may be differently recruited depending on the type of the required action (response mode: between vs. within hand responses). More precisely, categorizing two-handled objects by means of two fingers of the same hand may lead to the activation of abstract spatial codes given that no effector-specific component is at play in such a situation. In contrast, categorizing the same two-handled objects by means of the index fingers of each hand may lead to the activation of motoric factors due to the involvement of an effector-specific component of action. Consistent with this explanation, Iani et al. (2011) found that different response requirements affected the processing stage of irrelevant stimulus information. They presented participants with photographs of one-handled graspable objects and asked them to respond according to the vertical orientation of stimuli (upward or inverted orientation) by lifting one of two fingers and, either move it toward a lateralized button (Experiment 1), or move it toward a rectangular area located below the stimulus itself (Experiment 2). Each stimulus could be presented to the left or right of fixation (as in the classical Simon paradigm), and with its handle oriented to the left or right of the display. Both stimulus location and position of the object's graspable part were irrelevant to task performance. Nevertheless, they found that stimulus location and handle orientation affected response selection at different points in time in Experiment 1 and at the same point in time in Experiment 2. Therefore, they demonstrated that the processing stage and the resulting mechanism involved hinged on the specific type of response required from participants in each experiment.

Overall, evidence from the present study seems to suggest that the action potentiation and spatial codes mechanisms may be differently recruited as a function of the required action (i.e. response mode).

Future research may further develop the study of correspondence effect with grasped two-handled objects testing whether other response modes (e.g. grasping movements) produce similar results.

Figures captions

Fig. 1. Illustration of the four experimental conditions to Experiment 1. In the example, instructions required to respond with the left index finger to kitchen objects and with the right index finger to spare time objects. Note that elements are not drawn to scale.

Fig. 2. Illustration of the four experimental conditions to Experiment 2. In the example, the instructions required to respond with the left index finger to kitchen objects and with the right index finger to spare time objects. Note that elements are not drawn to scale.

Fig. 3. Illustration of the four experimental conditions to Experiment 3. In the example, instructions required to respond with the middle finger of the left hand to kitchen objects and with the index finger of the left hand to spare time objects. Note that elements are not drawn to scale.

Fig. 4. Mean RTs as a function of Condition (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) for all three Experiments. Bars are Mean Standard Errors corrected for within-participant designs (Loftus & Masson, 1994). Asterisks denote significant differences (*p < .05; ** p < .01; *** p < .001).

Fig. 5. Mean percentages of error as a function of Condition (Object Alone, Compatible Grasping, Incompatible Grasping, Two-Handed Grasping) for all three Experiments. Bars are Mean Standard Errors corrected for within-participant designs (Loftus & Masson, 1994). Asterisks denote significant differences (** p < .01; *** p < .001).

Fig. 6. The hand-to-response correspondence effect in all three Experiments. Bars are Mean Standard Errors corrected for within-participant designs (Loftus & Masson, 1994).

Fig. 7. The temporal dynamics of the hand-to-response correspondence effect in Experiments 1-3. Bars are Mean Standard Errors corrected for within-participant designs (Loftus & Masson, 1994).

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