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# The unimanual handle-to-hand correspondence effect: evidence for a location coding account

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## Abstract

The handle-to-hand correspondence effect refers to faster and more accurate responses when the responding hand is aligned with the graspable part of an object tool, compared to when they lay on opposite sides. We performed four behavioral experiments to investigate whether this effect depends on the activation of grasping affordances (affordance activation account) or is to be traced back to a Simon effect, resulting from the spatial coding of stimuli and responses and from their dimensional overlap (location coding account). We manipulated the availability of a response alternative by requiring participants to perform either a unimanual go/no-go task (absence of a response alternative) or a joint go/no-go task (available response alternative) and the type of response required (button-press or grasping response). We found no handle-to-hand correspondence effect in the individual go/no-go task either when a button-press (Experiment 1A) or a grasping (Experiment 2A) response was required, whereas a significant effect emerged in the joint go/no-go task, irrespective of response modality (Experiments 1B and 2B). These results do not support the idea that complex motor affordances are activated for meaningful objects, but are rather consistent with the more parsimonious location coding account.

## Introduction

Perception of objects or visual scenes can influence our motor behavior in an automatic, involuntary way. For instance, it has been widely shown that when pictures of objects (e.g., kitchen tools like cups or mugs) are presented in the center of the participants' visual field and with their handle jutting left- or rightward, responses are typically

faster and more accurate when the orientation of the handle corresponds to the location of the response, compared to when there is no spatial correspondence between them (i.e., handle-to-hand correspondence effect, Tucker & Ellis, 1998; see also Iani, Baroni, Pellicano, & Nicoletti, 2011; Ottoboni, Iani, Tessari, & Rubichi, 2013; Riggio et al., 2008; Iani, et al., 2018). This effect was employed to investigate the affordance activation hypothesis, according to which the perception of an object tool, beyond the extraction of mere perceptual features such as color, shape, size, and location orientation also activate actions which are consistent with its identity and its canonical use (e.g., Bub & Masson, 2010; Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012; Masson, Bub, & Breuer, 2011; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010b). According to this view, a perceived object activates appropriate grasping gestures whenever its identity and its functional meaning are recognized by the perceiver: whether these gestures will involve the left or the right hand will depend on the left- or rightward orientations of the object handle (variable affordances; see Borghi & Riggio, 2015; Pellicano, Thill, Ziemke, & Binkofski, 2011, see also Pellicano, Borghi, & Binkofski, 2017a). As a result, responses to a graspable object become faster and more accurate when the responding hand is aligned with its left- or rightward jutting handle, compared to when it is not.

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More recently, the explanation of the handle-to-hand correspondence effect in terms of affordance activation has been questioned by a number of studies that support an alternative location coding account (Cho & Proctor, 2010). According to this account, 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 correspond or not with the response spatial code, thus generating a basic stimulus–response (S–R) spatial correspondence effect (Cho & Proctor, 2011; 2013; Lien, Jardin, & Proctor, 2013; Lien, Gray, Jardin, & Proctor, 2014; Song, Chen, & Proctor, 2014; see Proctor & Miles, 2014 for a review). In other words, the handle-to-hand correspondence effect would correspond to an object-based Simon effect (Cho & Proctor, 2010), that is, to the far preceding evidence that stimulus location (or orientation) can influence motor responses (e.g., button presses) even if it is task -irrelevant (see Simon, 1990; Pellicano, Iani, Rubichi, Ricciardelli, Borghi & Nicoletti, 2010a; see Proctor & Vu, 2006 for a review). Most recently, such an object-based Simon effect was also observed when visual asymmetries were provided by object parts different from the handle (e.g., a flashlight bulb, see Pellicano et al., 2010b; or the jutting spout of a teapot, see Cho & Proctor, 2011; Pellicano, Koch, & Binkofski, 2017b). Furthermore, Pellicano et al. (2017b) went beyond the original formulation of the location coding account. They provided evidence that the spatial coding of visual objects is not produced by mere structural asymmetries in their body, but depend on higher-level iconic representations of depicted action directions (e.g., a plausible pouring action toward a second object).

The Simon effect is thought to depend on the dimensional overlap between stimulus and response sets (Kornblum, Hasbroucq, & Osman, 1990), that is, when both stimulus and response alternatives share the same spatial codes (e.g., left and right). Within this condition, the stimulus determines the automatic activation of the ipsilateral response (e.g., stimulus on the right—automatic activation of the right response). When the required (correct) response and the automatic one are the same, the selection of the correct response is facilitated. On the contrary, when the required response and the automatic one differ, the automatic response must be inhibited to allow for the selection of the correct response; this will slow down the performance and make it more error prone.

To note, the dimensional overlap between the stimulus and response sets is a necessary condition for the emergence of the Simon effect. Indeed, when no dimensional overlap exists between stimulus and response sets, there is no automatic response activation and, as a consequence of this, no Simon effect can emerge. This is the case when a go/no-go task is employed in place of a choice-reaction task within a

Simon paradigm. In this variant, participants have only one response button at their disposal and are instructed to press it in response to only one of two possible stimuli. It has been shown that, even though the response button is physically located in the left or in the right hemispace of the participant, and corresponds to the stimulus location on half of the trials, no Simon effect is typically observed (e.g., Berlucchi, Crea, Di Stefano, & Tassinari, 1977; Hommel, 1996; Lugli, Iani, Nicoletti, & Rubichi, 2013, Lu & Proctor, 1995; see also Ansorge & Wühr, 2004 for a response-discrimination account of the Simon effect).

As a confirmation of the crucial role of S–R dimensional overlap, it has been observed that when a go/no-go Simon task is distributed between two participants (i.e., joint go/no-go paradigm) the Simon effect turns significant (Sebanz, Knoblich, & Prinz, 2003; 2005). In this paradigm, two participants sit alongside each other and operate one of two left and right buttons: one participant is instructed to press her/his assigned button to respond to one nonspatial feature of the stimulus, while the other participant has to press the other button to respond to the alternative nonspatial feature. Even though each participant performs her/his go/no-go Simon task, a significant Simon effect is typically observed (joint or social Simon effect). On the one hand, this finding has been taken as evidence that the two participants share a common representation of the full task set (i.e., co-representation account), which is assumed to be a dedicated, automatic social process (Sebanz, Bekkering, & Knoblich, 2006; Sebanz & Knoblich, 2009; Ferraro, Iani, Mariani, Milanese, & Rubichi, 2011; Ferraro, Iani, Mariani, Nicoletti, Gallese, & Rubichi, 2012; Milanese, Iani, & Rubichi, 2010). On the other hand, a different interpretation has been proposed for the social element, that is, each participant forms representations of the co-actor and his actions exploiting them to shape and optimize his own task set (i.e., referential coding account—Dolk, Hommel, Prinz, & Liepelt, 2013; Dolk et al., 2014; Dolk & Prinz, 2016; Prinz, 2015; see Lugli, Iani, Milanese, Sebanz, & Rubichi, 2015). Indeed, beyond the theoretical differences between these two approaches, it stays the crucial evidence for the purposes of the present study that the presence of a confederate participant and of his/her actions creates the preconditions for the (re)occurrence of the Simon effect as it (re-)establishes the spatial representation of response alternatives (left–right), and their overlap with the stimulus set (e.g., Ciardo, Lugli, Nicoletti, Rubichi, & Iani, 2016; see also Dittrich, Rothe, & Klauer, 2012, and Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013 for an explanation of the joint Simon effect in terms of spatial-coding account).

Differently from the Simon effect, affordance effects should be independent from basic dimensional overlaps between stimuli and responses. Rather, affordances are thought to rely on more complex representations of stimulus

manipulation. Evidence supporting this view is provided by studies showing affordance correspondence effects in unimanual go/no-go tasks. For instance, Tucker and Ellis (2001) investigated the effects of visual objects on motor responses during a categorization task. The responses consisted in unimanual precision or power grasps that could be compatible or incompatible with the size of observed graspable objects. They observed that size–grasp compatibility significantly speeded up participant response times. More recently, De Stefani et al. (2014) presented participants with coffee cups that could be randomly black and white, with the handle pointing to the right or to the left. The objects were presented at reachable and unreachable distances from the participant's body. When the cup was white, participants had to pantomime with their right hand an appropriate reach–grasp movement toward an end position that was 10 cm on the right of the cup, independently of handle orientation (i.e., go trials). When the cup was black, participants had to refrain from responding and wait for the next trial (i.e., no-go trials). A significant handle-to-hand correspondence effect was observed in the kinematic measures of the reach–grasp responses: when the cup was reachable and the handle was in the left side, noncorresponding with the grasping right hand, in which maximal finger aperture was enlarged compared to the corresponding handle-to-hand alignment (handle on the right), suggesting an adaptation of the gesture to the cup body size instead of the cup handle size.

However a recent study by Roest, Pecher, Naeije, and Zeelenberg (2016) provided evidence in part contrasting with an affordance activation account. They investigated a handle-to-hand correspondence effect (that they named alignment effect, p. 1665) through measures of lift-off time (i.e., the time from the onset of the stimulus to the start of the movement), and movement time (i.e., the time from the start of the movement to the grasping of the response device). Their results showed an alignment effect in a left–right choice-reaction task only for the lift-off time (Experiment 1). However, with a go/no-go task this effect reversed (Experiment 2), and became nonsignificant (Experiment 3) for both lift-off and movement times. They concluded that the alignment effects in the CRT of Experiment 1 was most likely due to task-induced competition, either between the left and right limb at the response level (Bub & Masson, 2010) or between abstract spatial codes (e.g., Cho & Proctor, 2010).

In the present study, we moved from the assumption that object grasping affordances should not be affected by changes in the experimental task that bring to the involvement of one hand as the only effector (i.e., no response alternatives are given), compared to when both the hands are involved (i.e., left/right response alternatives are given). Indeed, the motor repertoire that characterizes object manipulation, which is supposed to be automatically activated at stimulus perception, is not supposed to

change when a unimanual go/no-go task is required instead of a bimanual choice-reaction task (a task commonly employed to investigate affordance effects). Furthermore, the upright orientation of graspable objects is more plausible to facilitate the activation of grasping affordances compared to upside-down orientation. For example, Ridoch, Edwards, Humphreys, West, and Heafield (1998) observed strong automatic grasp of objects handles in a patient with cortico-basal degeneration. When a cup was upright oriented, a grasping action was cued by the orientation of its handle in relation to the patient's preferred hand. However, when the cup was upside down, this grasp action decreased even though the handle orientation was the same as when the cup was upright (see also Rounis & Humphreys, 2015).

In four experiments, we investigated the handle-to-hand correspondence effect when S–R dimensional overlap was removed from the experimental paradigm, as well as when it was reintroduced, and when two different response sets were employed.

In Experiment 1A, single participants performed a go/no-go task requiring a right hand button-press response to picture stimuli of graspable objects with their handle located on the left or on the right side. In Experiment 1B, the same task was performed by paired participants performing a joint go/no-go task. In Experiments 2A and 2B, the same stimulus materials were employed, but a precision grip response was required to perform a single and joint go/no-go task, respectively. Furthermore, in Experiment 1A and 2A, affordance activation was supported by assigning upright object stimuli to go trials, and upside-down object stimuli to no-go trials.

The emergence of a handle-to-hand correspondence effect in Experiments 1A and 1B would support the idea that the effect is due to the activation of object affordances which emerge irrespective of the unimanual nature of the task, since they are independent of basic spatial representations of stimuli and responses and of their dimensional overlap. Conversely, the lack of a handle-to-hand correspondence effect in the individual go/no-go task (Experiment 1A) and its emergence in the joint go/no-go task (Experiment 1B) would support the location coding account for the handle-to-hand correspondence effect thus stating the crucial role of basic S–R dimensional overlap also within rich visual information. In Experiments 2A and 2B, motor responses reproduced the actual grasping action required by the object stimuli. This manipulation was expected to increase the chances to activate consistent grasping affordances with respect to Experiment 1, thus providing better preconditions for the emergence of a handle-to-hand effect in both the individual go/no-go condition (Experiment 2A) and in the joint go/no-go condition (Experiment 2B).

## Experiments 1A and 1B

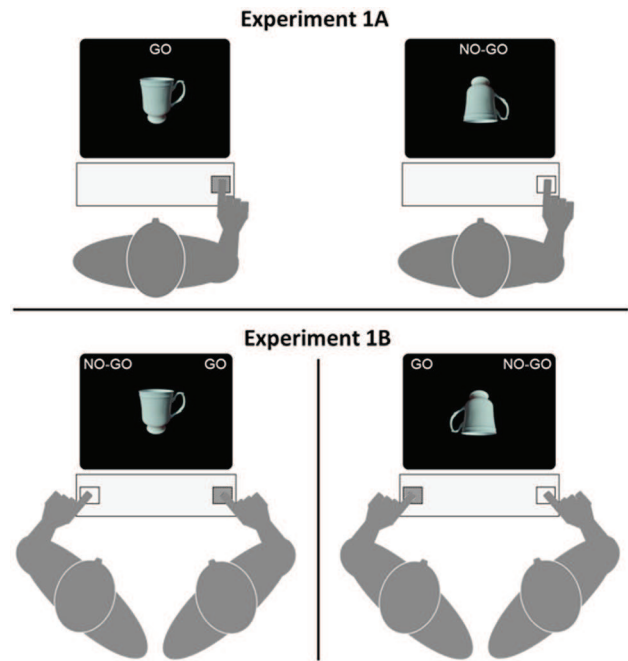
### Materials and methods

*Participants* 72 undergraduate students volunteered to participate in the study (56 from the University of Bologna and 16 from RWTH Aachen University). 24 students (19 females, 5 males; mean age 21.33 years; SD 1.65 years) participated in Experiment 1A, while 48 students (32 females, 16 males; mean age 23.74 years; SD 2.78 years) participated in Experiment 1B. In Experiment 1A participants performed a go/no-go task in which they were required to press a lateralized button with one hand to upright stimuli, while ignoring upside-down stimuli. In Experiment 1B, participants were randomly paired, and each pair performed a joint go/no-go task.

All participants were right-handed by self-report, reported normal or corrected-to-normal vision, and were naïve with regard to the experimental hypotheses. The present experiments and the following ones were approved by the local ethics committee and were conducted in accordance with the ethical standards laid down in the Declaration of Helsinki. All participants gave their oral informed consent to participate to the study.

*Apparatus and stimuli* The experiment was carried out in a dimly lit and noiseless room. Participants were seated facing a 17" screen (1024 × 768 resolution) driven by a 700 MHz PC. The eye distance from the screen was approximately 60 cm. Stimulus presentation, response timing, and data collection were controlled by the E-Prime Professional v2.0 software (<https://www.psnet.com>). A white fixation cross (1.1° × 1.1° of visual angle) and the target stimulus (covering a 5° × 5° area) were presented on a black background at the center of the screen. Target stimuli were grayscale photographs (see Riggio et al., 2008) of four kitchen objects (a coffee pot, a milk jug, a teacup, and a beer mug) all sharing a jutting handle on one side, and centered on the base of their body. Each stimulus was displayed in four different configurations: two vertical orientations (upright vs. 180° rotated/upside down) × two horizontal orientations (handle on the left vs. handle on the right, which is compatible with a left and a right hand grasp, respectively) for a total of 16 stimuli.

In Experiment 1A, the screen and the body of the participant were centered with respect to a vertical midline drawn on the table. One button box was placed on the table 10 cm on the left or the right of the vertical midline. Responses were emitted by pressing this button with the left or the right hand, respectively (Fig. 1, upper panel). In Experiment 1B, two participants sat side by side in front of the monitor and at the same distance from the table midline. Two button boxes were placed on the left and on



**Fig. 1** Schematic representation of a handle-to-hand corresponding trial for the individual go/no-go Experiment 1A (upper panel), and the joint go/no-go Experiment 1B (bottom panel); both with button press responses and vertical discrimination task. In Experiment 1A, the responding hand and button was counterbalanced between-participants. In Experiment 1B (paired participants) a go trial for one participant was a no-go trial for the other participant; the stimulus-response mapping was counterbalanced-between-participants

the right side, at 10 cm from the midline. The participant on the left pressed the left button with the index finger of her/his left hand, whereas the participant on the right pressed the right button with the index finger of her/his right hand (Fig. 1, lower panel). In both the experiments for each participant, the non-responding hand was kept below the table.

*Procedure* At the beginning of each trial, the fixation cross was presented for 1000 ms, followed by the target stimulus, which remained on the screen for a maximum of 1000 ms or until a response was emitted.

In Experiment 1A a go/no-go task was implemented: half the participants had the response button located on the left side and pressed it with the index finger of their left hand, whereas for the other half the button was located on the right side and pressed with the right index finger. Participants were instructed to press the response button to upright stimuli (i.e., go stimuli) and to refrain from responding when stimuli were upside down (i.e., no-go stimuli). In Experiment 1B, a joint go/no-go task was implemented: for half of the pairs, the participant on the left was instructed to press her/his response button only to upright stimuli, while the participant on the right was instructed to press her/his response button only

to upside-down stimuli. For the other half of the pairs, response assignments were reversed.

In both the experiments, the orientation of the object's handle was task irrelevant and had to be ignored. Thus, the location of the responding hand of the single participant (Experiment 1A) and of the paired participants (Experiment 1B) could either spatially correspond with the horizontal orientation of the handle (i.e., corresponding trials) or not (i.e., non-corresponding trials). As soon as a correct response was emitted, the actual RT was displayed in the middle-bottom part of the screen for 1000 ms. If a response to no-go stimuli or no response to go stimuli occurred, error and omission feedbacks were provided for 1000 ms together with a low pitch tone.

Both experiments comprised 12 training trials followed by 384 experimental trials divided into three blocks of 128 trials each. Stimuli were randomized within each block. Participants took short breaks between the blocks. The duration of the experiments was about 30 min.

## Results and discussion

In Experiment 1A, responses to no-go trials (i.e., errors) were 1.1% of the total trials while omitted responses to go trials were 0.3% of the total trials. Responses that were two standard deviations below (0.7%) or above (2.2%) each participant's overall mean were excluded from the analyses. In Experiment 1B, responses to no-go trials were 1.0% of the total trials, while omitted responses to go trials were 0.3% of the total trials. Responses that were two standard deviations below (0.1%) or above (1.3%) each participant's overall mean were excluded from the analyses.

First, we wanted to assess any potential difference in Experiment 1B between participants who responded to upright stimuli and those who responded to upside-down stimuli. To this end, correct RTs and error rates (i.e., responses to no-go trials—ERs) were submitted to two analyses of variance (ANOVAs) with Orientation (upright

vs. upside-down stimuli) as between-subjects variable, and Correspondence (handle-to-hand corresponding vs. non-corresponding pairings) as within-subject variable. When necessary, post hoc comparisons were performed using paired samples *t* tests and by correcting the *p* value on the basis of the number of planned comparisons (Bonferroni correction).

For RTs, the main effect of Correspondence was significant  $F(1, 46) = 32.965, p < .001, \eta^2_p = 0.42$ , with faster RTs in handle-to-hand corresponding relative to non-corresponding trials (400 vs. 411 ms). The main effect of Orientation was significant,  $F(1, 46) = 5.636, p = .022, \eta^2_p = 0.11$ , with slower responses to upside down (420 ms) than to upright (391 ms) stimuli. The interaction between the two factors did not reach significance,  $F(1, 46) < 1$ , meaning that the magnitude of the correspondence effect did not differ between upright and the upside-down orientation groups. For ERs, the main effect of Correspondence was significant,  $F(1, 46) = 4.563, p = .038, \eta^2_p = 0.09$ , with a lower percentage of errors in handle-to-hand corresponding than in non-corresponding trials (1.7 vs. 2.3%). Neither the main effect of Orientation,  $F(1, 46) = 1.344, p = .252, \eta^2_p = 0.03$  (upright stimuli = 2.3%, upside-down stimuli = 1.7%), nor the Orientation  $\times$  Correspondence interaction,  $F(1, 46) = 2.031, p = .161, \eta^2_p = 0.04$ , reached significance (see Table 1).

Mean correct reaction times (RTs) for the two experiments were then submitted to mixed-design analyses of variance (ANOVA) with Experiment (Experiment 1A vs. Experiment 1B) as between-subjects variable, and Correspondence (handle-to-hand corresponding vs. non-corresponding trials) as within-subjects variable. Firstly, we compared responses to upright stimuli of all the participants in Experiment 1A to responses of half the participants in Experiment 1B who responded to upright stimuli. Secondly, we compared the same responses to upright stimuli in Experiment 1A to the responses of the other half the participants of Experiment 1B who responded to upside-down stimuli. All statistical tests were performed in SPSS (IBM, USA). When necessary, paired samples *t* tests were performed as post hoc

**Table 1** Mean response times (in milliseconds), and error rates (in percentage) as a function of object vertical Orientation (upright vs. upside down) and Correspondence (handle-to-hand corresponding vs. non-corresponding pairings)

	Experiment												
	1A		1B				2A		2B				
	Upright	Upside down	Upright	Upside down	Upright	Upside down	Upright	Upside down	Upright	Upside down	Upright	Upside down	
	RTs	ERs	RTs	ERs	RTs	ERs	RTs	ERs	RTs	ERs	RTs	ERs	
Handle-to-hand corresponding	391	2.5	385	2.2	414	1.2	390	2	372	2.8	383	1.6	
Handle-to-hand noncorresponding	393	2.3	397	2.4	425	2.3	390	2.3	379	3.9	390	2.9	
Correspondence effect		2	0.2	12*	0.2	11*	1.1*	0	0.3	7*	1.1	7*	1.3

The correspondence effect is computed as the difference in reaction times and error rates between non-corresponding and corresponding trials

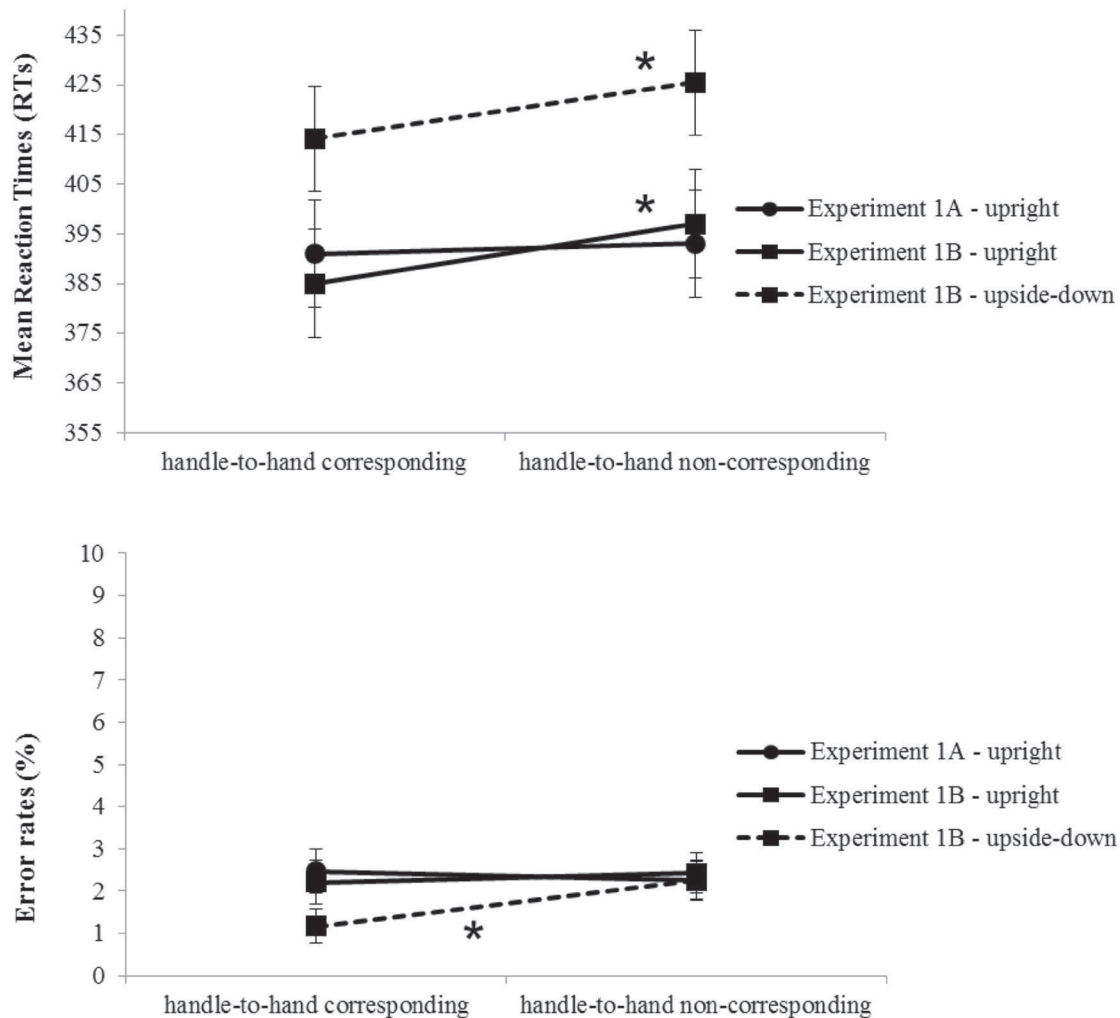
Asterisks denote significant effects

comparisons with Bonferroni corrected  $p$  value. An open-source tool was used to compute Cohen's  $d_z$  effect size for the  $t$  tests (<http://www.cognitiveflexibility.org/size/>).

**Experiment 1A vs. 1B upright stimuli** Mean RTs from Experiment 1A (392 ms) and Experiment 1B (391 ms) did not differ from each other,  $F < 1$ ,  $\eta^2_p = 0.0001$ . The main effect of Correspondence was significant, with faster RTs in handle-to-hand corresponding (388 ms) than in handle-to-hand non-corresponding (395 ms) trials,  $F(1, 46) = 11.620$ ,  $p = .0014$ ,  $\eta^2_p = 0.20$ . The interaction between Experiment and Correspondence was also significant,  $F(1, 46) = 6.451$ ,  $p = .015$ ,  $\eta^2_p = 0.12$ . Paired-sample  $t$  tests showed no significant handle-to-hand correspondence effect in Experiment 1A (391 vs. 393 ms),  $t(23) = 0.758$ ,  $p = .456$ ,  $d_z = 0.16$ , and a significant effect (i.e., with upright stimuli) in Experiment 1B (385 vs. 397 ms),  $t(23) = 3.630$ ,  $p = .0014$ ,  $d_z = 0.74$ , (Bonferroni-corrected  $p$  level = 0.025) (see Table 1;

Fig. 2 upper panel). For ERs no source of significance was observed,  $F_s(1, 46) < 1$ .

**Experiment 1A-upright vs. Experiment 1B-upside-down stimuli** The main effect of Experiment was not significant (Experiment 1A = 392 ms vs. Experiment 1B = 420 ms),  $F(1, 46) = 3.459$ ,  $p = .069$ ,  $\eta^2_p = 0.07$ . The main effect of Correspondence was significant, with faster RTs in handle-to-hand corresponding (403 ms) than in handle-to-hand non-corresponding (409 ms) trials,  $F(1, 46) = 15.763$ ,  $p < .001$ ,  $\eta^2_p = 0.26$ . The interaction between Experiment and Correspondence was also significant,  $F(1, 46) = 8.573$ ,  $p = .005$ ,  $\eta^2_p = 0.16$ . Paired-sample  $t$  tests showed that the effect of Correspondence was significant in Experiment 1B (i.e., upside-down stimuli only: 414 vs. 425 ms),  $t(23) = 4.749$ ,  $p < .001$ ,  $d_z = 0.99$ , compared to the above displayed non-significant effect in Experiment 1A (Bonferroni-corrected  $p$  level = 0.025) (see Table 1; Fig. 2 upper panel). For ERs, the



**Fig. 2** Mean reaction times (RTs) in milliseconds, and error rates (ERs) in percentage as a function of Correspondence (handle-to-hand corresponding vs. non-corresponding trials) for Experiments 1A and

1B. Asterisks denote significant differences. Bars represent standard errors of the mean

main effects of Correspondence was not significant (1.8% vs. 2.3%),  $F(1, 46) = 2.439$   $p = .125$ ,  $\eta^2_p = 0.05$ . The main effect of Experiment was not significant too (Experiment 1A = 2.4% vs. Experiment 1B = 1.7%),  $F(1, 46) = 1.538$   $p = 0.221$ ,  $\eta^2_p = .03$ ; however, the Correspondence  $\times$  Experiment interaction was significant,  $F(1, 46) = 5.496$   $p = .023$ ,  $\eta^2_p = 0.11$ . The effect of Correspondence was significant in Experiment 1B (i.e., upside-down stimuli only: 1.2 vs. 2.3%),  $t(23) = 2.436$ ,  $p = .023$ ,  $d_z = 0.52$ , but not in Experiment 1A (2.5 vs. 2.3%),  $t(23) = 0.655$ ,  $p = .519$ ,  $d_z = 0.14$  (Bonferroni-corrected  $p$  level = 0.025) (see Table 1; Fig. 2 bottom panel).

The results of Experiments 1A and 1B speak against the affordance activation account. Indeed, according to this view the perceptual and motor meaningfulness of an object stimulus should not vary between a unimanual go/no-go task and a bimanual two-choice task. In other terms, the motor repertoire that characterizes object manipulation, including the appropriate hand, is not supposed to vary as a function of the available response set. In both the task situations, and peculiarly with objects presented in their upright canonical orientation, grasping affordances should be activated since participants' task requires access to the object's identity. Contrary to these predictions, no significant handle-to-hand correspondence effect was observed in the individual go/no-go task of Experiment 1A, while a significant effect emerged in the joint go/no-go task of Experiment 1B. The results of Experiment 1A replicated those observed for go/no-go versions of the Simon task employing simple, lateralized color stimuli and one response physically lateralized with respect to the body midline (Ansorge & Wühr, 2004; Lugli et al., 2013), while the results of Experiment 1B replicated those of previous studies using joint go/no-go tasks (e.g., Ferraro et al., 2012; Sebanz & Knoblich, 2009). The within-experiment analysis of Experiment 1B clarified that the vertical orientation of the object stimuli had no influence on the correspondence effect observed in the joint go/no-go tasks. Even if the responses to upside-down stimuli resulted significantly slower than responses to upright stimuli, this did not affect the size of the correspondence effect as indicated by the nonsignificant interactions between Orientation and Correspondence in both the joint go/no-go experiments. This made the following between-experiments results even clearer, as the presence of a correspondence effect in the joint tasks and its absence in the individual ones could only be attributed to task differences. Taken together, the results are consistent with the alternative location coding account (Cho & Proctor, 2010), according to which the handle-to-hand correspondence effect is a Simon-like effect that depends on the overlap between stimuli and responses abstract spatial codes (Kornblum et al., 1990). Thus, as for the individual go/no-go Simon task, the structure of the response set of Experiment 1A required a decision between

the two options of pushing or not the response button. However, as these two options were not spatially distinct, spatial response codes were not created so that no S-R dimensional overlap was possible and, as a consequence, no correspondence effect was observed (see the response discrimination account of the Simon effect, Wühr & Ansorge, 2007; Wühr et al., 2008). Differently, in the joint go/no-go task used in Experiment 1B, a Simon-like effect was re-instated because, due to either to co-representation of the task set (e.g., Sebanz et al., 2006), or the shaping of individual task set on the basis of the co-actor actions (i.e., referential coding account, Dolk & Prinz, 2016; Prinz, 2015), two response alternatives were available and overlapped with the stimulus locations.

## Experiments 2A and 2B

In Experiments 1A and 1B, responses were key presses. As suggested by Bub and Masson (2010; see also Bub, Masson, & Kumar, 2018), handle-to-hand correspondence effects emerging when left-right key-press responses are required may stem from spatial coding. Indeed, motor affordances are more likely to emerge when responses are reach-and-grasp actions. Given these considerations, in Experiment 2A participants performed a go/no-go task executing a lateralized precision grasp with one hand. We hypothesized that the execution of object-appropriate grasping responses would create the conditions for the activation of motor affordances and, as a consequence of this, for the emergence of a significant handle-to-hand correspondence effect in the unimanual go/no-go task. It is plausible that stronger affordance effects would emerge when the required action more closely resembles the one afforded by the stimulus (e.g., Couth, Gowen, & Poliakoff, 2014; Iani et al., 2011). For instance, Fagioli, Hommel, and Schubotz (2007) provided evidence that the processing of object shape was favored when grasping responses were employed, whereas location information was privileged with reaching responses. More specifically, Pavese and Buxbaum (2002) demonstrated that a distracting affording stimulus slowed RTs for reaching and grasping responses more than for a button-press response. Similarly, Bub and Masson (2010) showed that a reach and grasp action reliably yielded compatibility effects, whereas no such effects were found for a button-press response.

In Experiment 2B, paired participants performed a joint go/no-go task in which each participant was required to respond to either upright or upside-down stimuli by emitting a precision grasp response. The aim of the experiment was to assess whether, as occurred in Experiment 1B, the use of a joint go/no-go paradigm allows for the emergence of the handle-to-hand correspondence effect.



## Materials and methods

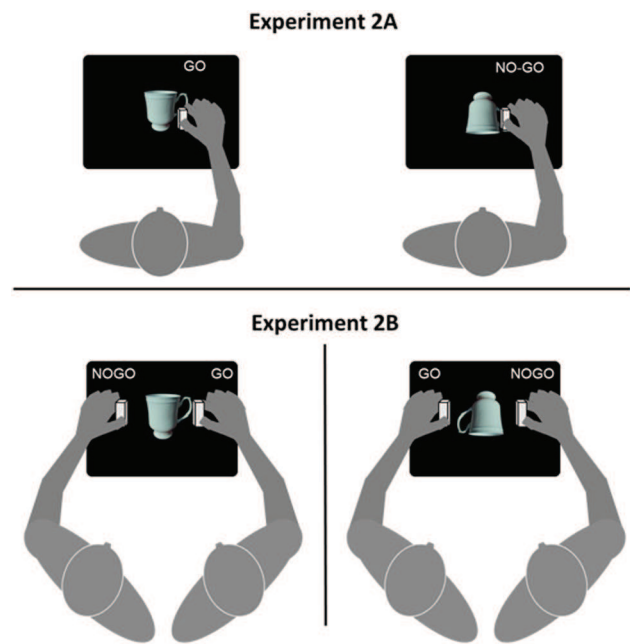
*Participants* 72 undergraduate students from the University of Bologna and from RWTH Aachen University volunteered to participate in the study. 24 students (16 females, 8 males; mean age 23.0 years; SD 3.10) took part in Experiment 2A and performed a go/no-go task. 48 students took part in Experiment 2B (34 females, 14 males; mean age 22.52 years; SD 3.92 years); they were randomly paired and each pair performed a joint go/no-go task. All reported normal or corrected-to-normal vision were right-handed by self-report and were naïve with regard to the hypotheses of the experiment.

*Apparatus, stimuli and procedure* In Experiment 2A, apparatus, stimuli and procedure were the same as in Experiment 1A, except for the fact that responses mimicking a fine grasp movement (very similar to the one proper for the depicted objects) were employed instead of button presses. Half the participants responded with the right hand and the other half with the left hand. They placed their elbow on the table at approximately 25 cm from the screen while holding a 15 mm-thick button box between the thumb and the index finger. The button box with the two grasping fingers was held at 1 cm distance from the screen surface, on its vertical midline, and 10 cm laterally to its center (i.e., on the left or on the right side of the stimulus presentation area for participants responding with the left or the right hand, respectively). Indeed, this posture allowed them to mimic a precision grip consistent with the size and the shape of the objects handles (see the schematic representation in Fig. 3, upper panel).

In Experiment 2B, participants sat side by side in front of the monitor, both holding one button box with the same posture and the same grasp movements as in Experiment 2A. Specifically, the participant on the left performed the grasping response with her/his left hand, whereas the participant on the right performed it with her/his right hand (Fig. 3, bottom panel). In both the experiments, the responding hands and their grasping movement could be compatible with the orientation of the objects' handle (i.e., corresponding trials) or incompatible with it (i.e., non-corresponding trials; in which the grasping gesture was produced but with the handle on the opposite side).

## Results and discussion

In Experiment 2A, responses to no-go trials (i.e., errors) were 1.1% of the total trials while omitted responses to go trials were 0.3%. Responses that were 2 standard deviations below (0.1%) or above (2.2%) each participant's overall mean were excluded from the analyses. In Experiment 2B, responses to no-go trials were 1.4% of the total trials while omitted responses to go trials were 0.1%. Responses that



**Fig. 3** Schematic representation of Experiment 2A and Experiment 2B, both with precision grasp responses and vertical discrimination task. Handle-to-hand correspondence is represented for each correct response. Upper panel: Individual go/no-go task performed in Experiment 2A; the responding hand and button was counterbalanced between-participants. Lower panel: joint go/no-go task performed in Experiment 2B; stimulus-response mapping was counterbalanced between-participants

were 2 standard deviations below (0.2%) or above (2%) each participant's overall mean were excluded from the analyses.

The first analysis was performed on the data of Experiment 2B to control for possible effects of object vertical orientation between the groups. Correct RTs and ERs were submitted to separate ANOVAs with Orientation (upright vs. upside-down stimuli) as between-subjects variable, and Correspondence (handle-to-hand corresponding vs. non-corresponding pairings) as within-subject variable. When necessary, paired samples *t* tests were performed as post hoc comparisons with Bonferroni-corrected *p* value.

For the RTs, the main effect of Orientation did not reach significance,  $F(1, 46) < 1$ ,  $p = .381$ ,  $\eta_p^2 = 0.02$  (375 and 386 ms for upright and upside-down stimuli, respectively). The main effect of Correspondence was significant,  $F(1, 46) = 24.094$ ,  $p < .001$ ,  $\eta_p^2 = 0.34$ , with faster RTs in handle-to-hand corresponding than in non-corresponding trials (377 vs. 385 ms). The interaction between Orientation and Correspondence was not significant,  $F(1, 46) < 1$ , indicating that the magnitude of the correspondence effect did not differ between the upright and the upside-down orientation groups. For the ERs, the main effect of Correspondence was significant,  $F(1, 46) = 9.078$ ,  $p = .004$ ,  $\eta_p^2 = 0.16$ , with lower percentage of errors in handle-to-hand corresponding than

in non-corresponding trials (2.2 vs. 3.4%). Neither the main effect of Orientation,  $F(1, 46) = 2.928$ ,  $p = .094$ ,  $\eta_p^2 = 0.06$  (upright stimuli = 2.3%, upside-down stimuli = 3.4%), nor the Orientation  $\times$  Correspondence interaction,  $F(1, 46) < 1$ ,  $p = .865$ ,  $\eta_p^2 = 0.001$ , reached significance (see Table 1).

Mean correct reaction times (RTs) for the two experiments were then submitted to ANOVAs with Experiment (Experiment 2A vs. Experiment 2B) as between-subjects variable, and Correspondence (handle-to-hand corresponding vs. non-corresponding trials) as within-subjects variable. As in Experiment 1, we firstly compared responses to upright stimuli of all the participants in Experiment 2A to responses of half the participants of Experiment 2B who responded to upright stimuli. Secondly, we compared responses to upright stimuli in Experiment 2A to those of the other half the participants of Experiment 2B who responded to upside-down stimuli.

*Experiment 2A vs. 2B upright stimuli* Mean RTs from Experiment 2A (390 ms) and Experiment 2B (375 ms) did not differ,  $F < 1$ ,  $\eta_p^2 = 0.02$ . The main effect of Correspondence was significant with faster RTs in handle-to-hand corresponding (381 ms) than in non-corresponding (385 ms) trials,  $F(1, 46) = 6.013$ ,  $p = .018$ ,  $\eta_p^2 = 0.12$ . The interaction between Experiment and Correspondence was also significant,  $F(1, 46) = 4.577$ ,  $p = .038$ ,  $\eta_p^2 = 0.09$ . Paired-sample  $t$  tests clarified that there was no significant handle-to-hand correspondence effect in Experiment 2A (390 vs. 390 ms),  $t(23) = 0.203$ ,  $p = .841$ ,  $d_z = 0.04$ , whereas a significant handle-to-hand correspondence effect (with upright stimuli) was evident in Experiment 2B (372 vs. 379 ms),  $t(23) = 3.602$ ,  $p = .002$ ,  $d_z = 0.74$ , (Bonferroni-corrected  $p$  level = 0.025) (see Table 1; Fig. 4 upper panel). For ERs, the main effects of Correspondence was not significant (2.4 vs. 3.1%),  $F(1, 46) = 3.946$ ,  $p = .053$ ,  $\eta_p^2 = 0.08$ . The main effect of Experiment (Experiment 2A = 2.1% vs. Experiment 2B = 3.4%), as well as the Correspondence  $\times$  Experiment interaction were not significant,  $F(1, 46) = 3.781$ ,  $p = .058$ ,  $\eta_p^2 = 0.08$ , and  $F(1, 46) = 1.047$ ,  $p = .312$ ,  $\eta_p^2 = 0.02$ , respectively (see Table 1; Fig. 4 bottom panel).

*Experiment 2A-upright vs. Experiment 2B-upside-down stimuli* The main effect of Experiment was not significant (Experiment 2A = 390 ms vs. Experiment 2B = 386 ms),  $F < 1$ ,  $\eta_p^2 = 0.001$ . The main effect of Correspondence was significant with faster RTs in handle-to-hand corresponding (386 ms) than in non-corresponding (390 ms) trials,  $F(1, 46) = 6.145$ ,  $p = .017$ ,  $\eta_p^2 = 0.12$ . The Experiment  $\times$  Correspondence interaction was also significant,  $F(1, 46) = 4.777$ ,  $p = .034$ ,  $\eta_p^2 = 0.09$ . Paired-sample  $t$  tests confirmed that there was a significant handle-to-hand correspondence effect with upside-down stimuli in Experiment 2B (383 vs. 390 ms),  $t(23) = 3.374$ ,  $p = .003$ ,  $d_z = 0.76$  (Bonferroni-corrected  $p$  level = 0.025) (see Table 1; Fig. 4 upper panel). For ERs, the main effects of Correspondence was significant

(1.8 vs. 2.6%),  $F(1, 46) = 6.380$ ,  $p = .015$ ,  $\eta_p^2 = 0.12$ . The main effect of Experiment was not significant (Experiment 2A = 2.1% vs. Experiment 2B = 2.3%),  $F(1, 46) < 1$ ,  $\eta_p^2 = .001$ ; the Correspondence  $\times$  Experiment interaction was also not significant,  $F(1, 46) = 1.970$ ,  $p = 0.167$ ,  $\eta_p^2 = 0.04$ . (see Table 1; Fig. 4 bottom panel).

Hence, even though in Experiment 2A the response required to the participants was more similar to the action typically performed to interact with a given object, the activation of an affordance for a grasping action was not facilitated. Indeed, a handle-to-hand correspondence effect did not emerge when only one grasp response had to be emitted and there was no other agent in charge of the alternative response. Experiment 2B replicated the results of Experiment 1B and added further support to the idea that the handle-to-hand correspondence effect does not depend on the activation of affordances. Rather, it appears to depend on the spatial coding of both stimulus and response sets.

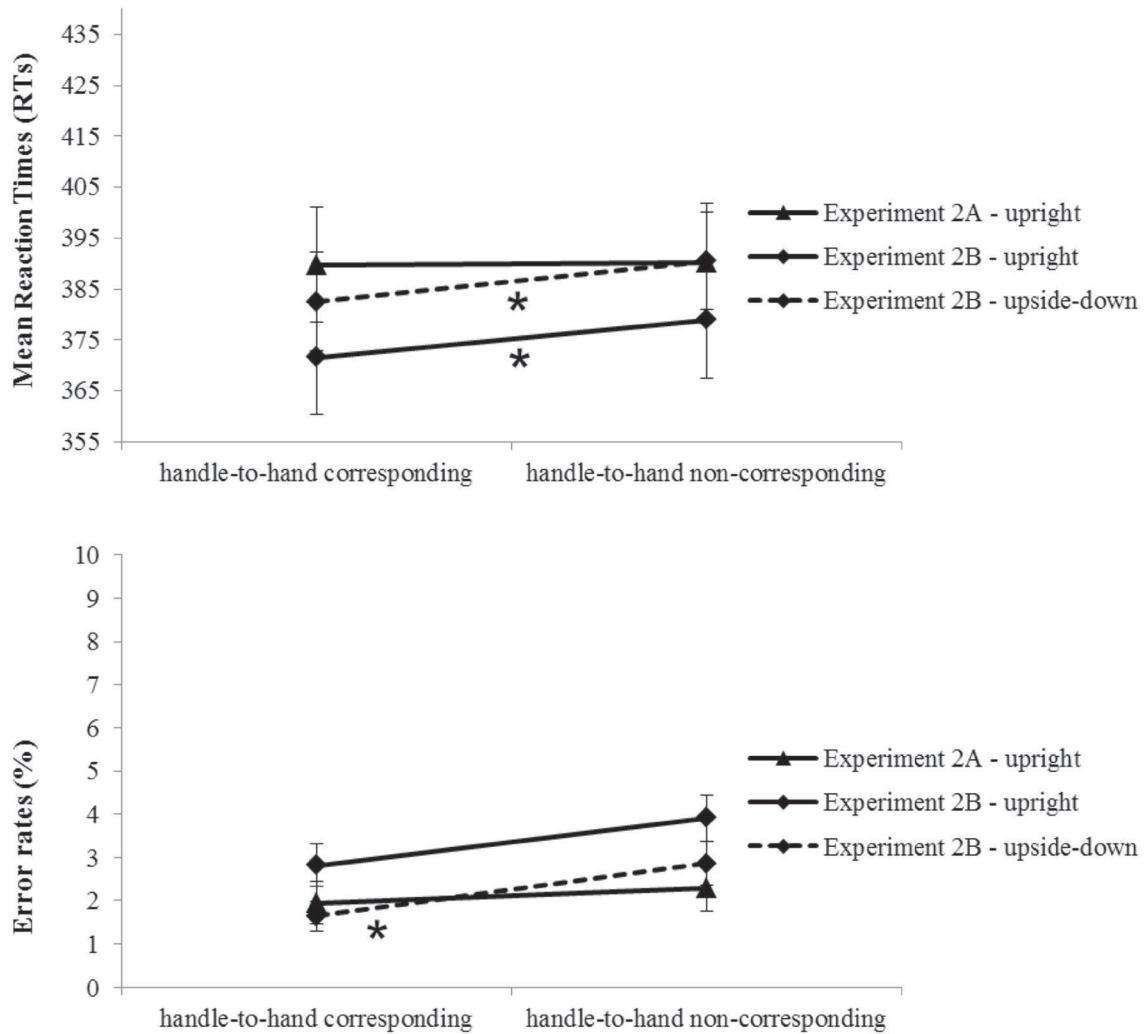
Furthermore, the within-experiment analysis of the joint go/no-go Experiment 2B showed no overall difference between responses to upright and upside-down stimuli, as well as no effect on the size of the correspondence effect. This confirms the conclusions provided for previous Experiments 1A and 1B that the presence of a correspondence effect in the joint task and its absence in the individual one could only be attributed to task differences.

## Distribution analyses

Overall, the absence of a correspondence effect in the individual relative to the joint go/no-go experiments did not fully rule out the possibility that affordances were active in the individual task. Indeed, grasp affordances might have required time to activate, affecting performance at slower RTs only. To test this possibility, distribution analyses of RTs (bin analyses) were run to investigate whether individual go/no-go correspondence effects were present at the slower RTs—a finding that would support the affordance activation account. More in general, these analyses also investigated possible differences in terms of RT distribution between individual and joint go/no-go tasks.

For the individual go/no-go tasks of Experiment 1A and 2A, RTs distributions as a function of handle-to-hand correspondence were divided into quintiles (bins), and the mean RT for each quintile was calculated. An ANOVA was run with Experiment (Experiment 1A vs. Experiment 2A) as between-subjects variable, and Bin (from bin 1 to bin 5) and Correspondence as within-subject variables.

Considering the way data were grouped, the Bin main effect necessarily turned out to be significant and was neither reported nor discussed. Neither the main effects of Experiment,  $F(1, 46) < 1$  and Correspondence,  $F(1, 46) < 1$ ,  $p = .508$ ,  $\eta_p^2 = 0.01$ , nor the Bin  $\times$  Correspondence and the



**Fig. 4** Mean reaction times (RTs) in milliseconds, and error rates (ERs) in percentage as a function of Correspondence (handle-to-hand corresponding vs. non-corresponding trials) for Experiments 2A and

2B. Asterisks denote significant differences. Bars represent standard errors of the mean

Bin  $\times$  Correspondence  $\times$  Experiment interactions,  $F_s(4, 184) < 1.047$ ,  $p_s < .385$ ,  $\eta^2_{p_s} < 0.02$ , reached significance. Thus, when the task was performed by one single participant (go/no-go task), the handle-to-hand correspondence effect was nonsignificant across bins, irrespective of response type (button press or precision grasp) (see Table 2).

For the joint go/no-go tasks of Experiment 1B and 2B, RTs distributions as a function of stimulus orientation and handle-to-hand correspondence were divided into quintiles (bins), and mean RT for each quintile was calculated. An ANOVA was run with Experiment (Experiment 1B vs. Experiment 2B) and Orientation (upright vs. upside down)

**Table 2** Correspondence effect size (ms) across quintiles (bins) for Experiments 1A and 1B, and for Experiments 2A and 2B

Bin	Experiment 1A	Experiment 1B		Experiment 2A	Experiment 2B	
	Upright	Upright	Upside down	Upright	Upright	Upside down
1	4	7	8	4	4	-2
2	1	10	9	1	7	5
3	0	14	11	0	6	6
4	1	14	14	-1	8	9
5	3	14	12	-2	9	11

as the between-subjects variables, and Bin (from bin1 to bin 5) and Correspondence as within-subject variables. The main effect of Experiment was significant,  $F(1, 92) = 8.090$ ,  $p = .005$ ,  $\eta_p^2 = 0.08$ , with slower RTs in Experiment 1B (405 ms) relative to Experiment 2B (380 ms). The main effect of Orientation was also significant,  $F(1, 92) = 4.930$ ,  $p = .029$ ,  $\eta_p^2 = 0.05$ , with faster RTs in the upright (383 ms) relative to the upside-down condition (402 ms). The two variables did not interact,  $F(1, 92) < 1$ ,  $p = .349$ ,  $\eta_p^2 = 0.01$ . The main effect of Correspondence was significant,  $F(1, 92) = 48.817$ ,  $p < .001$ ,  $\eta_p^2 = 0.35$  (388 vs. 397 ms) and it interacted with Experiment,  $F(1, 92) = 3.977$ ,  $p = .049$ ,  $\eta_p^2 = .04$ . Paired-sample  $t$  tests showed that the handle-to-handle correspondence effect was significant in both Experiments 1B (399 vs. 411 ms) and 2B (377 vs. 383 ms),  $t(47) = 6.011$  and  $3.840$ ,  $ps < .001$ ,  $d_z = 0.87$  and  $0.55$ , with a larger effect in Experiment 1B (12 ms) than in Experiment 2B (6 ms). The Bin variable only interacted with Correspondence,  $F(4, 368) = 6.009$ ,  $p < .001$ ,  $\eta_p^2 = .06$ . Paired-samples  $t$  tests showed that the correspondence effect was not significant at bin 1 (4 ms),  $t(95) = 1.983$ ,  $p = .050$ ,  $d_z = 0.21$ , and significant at bins 2–5 (8, 9, 11, and 12 ms)  $t(95) < 6.733$ ,  $ps < 0.001$ ,  $d_z > 0.63$  (Bonferroni corrected  $p$

level = .01). No other interaction reached significance  $F(4, 368) < 1$  (Fig. 5; Table 2).

The results of these analyses clearly ruled out the possibility that affordances were activated at slower RTs in the individual go/no-go tasks. Indeed, in both Experiments 1A and 2A the handle-to-hand correspondence effect for upright stimuli was nonsignificant across the bin distribution. In Experiments 1B and 2B, the size of the correspondence effect reached significance early in the RT distribution (bin 2) and remained significant across the distribution for both upright and upside-down stimuli.

Lastly, we also wanted to rule out an alternative explanation of our results: that the significant correspondence effect in the joint conditions and the non-significant effect in the individual conditions simply depended on overall RTs differences between the two tasks (at least between the upright groups). To discard this possibility, we have already showed that overall RTs did not differ between Experiment 1A (392 ms) and Experiment 1B (391 ms), and between Experiment 2A (390 ms) and Experiment 2B (375 ms),  $F_s < 1$ . To further address this point, we conducted extra distribution analyses that compared Experiment 1A and 1B, as well as Experiment 2A and 2B, for the upright condition

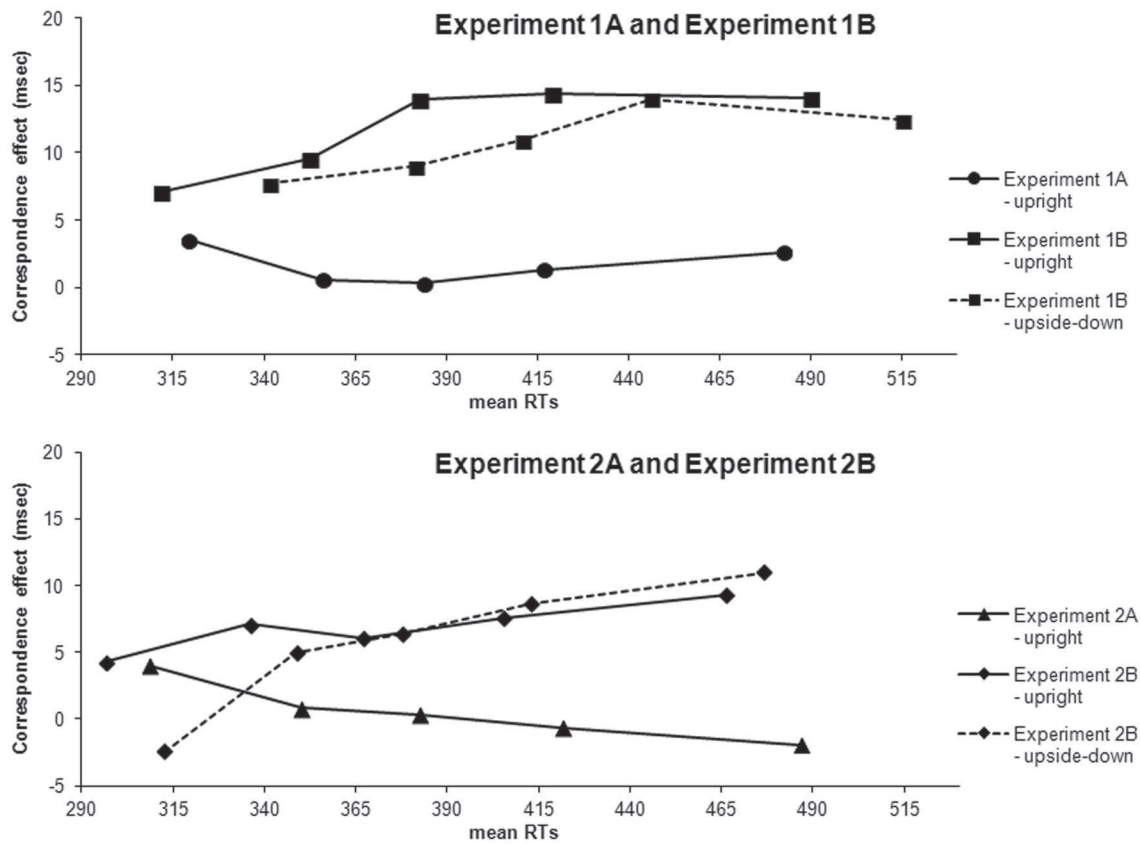


Fig. 5 Distribution analyses of RTs. The size of the correspondence effect (in milliseconds) plotted as a function of the mean RTs for each quintile

only. In both the analyses, the crucial Experiment  $\times$  Correspondence  $\times$  Bin interactions were not significant,  $F(4, 184) = 2.144, p = .081, \eta^2_p = 0.04$ , and  $F(4, 184) = 1.863, p = .119, \eta^2_p = 0.04$ , respectively. These results indicate that the already described pattern of results (i.e., the significant correspondence effect in the joint tasks, and the nonsignificant effect in the individual tasks) was independent of response speed, that is, was similar at fast and slow RT bins.

### Sequential analyses

To investigate the possible effects of previous handle-to-hand correspondence, as well as of previous go/no-go assignments, we conducted trial-to-trial sequential analyses (see Liepelt, Wenke, Fischer, & Prinz, 2011) in both the individual and joint go/no-go experiments. Responses that were 2 standard deviations below/above each participant's overall mean, incorrect responses in both current and preceding trials, as well as the first trial in each block were excluded from the analyses. Separate ANOVAs were conducted for the individual and joint tasks, and for the joint task for upright and upside-down stimuli. Mean RTs were computed as a function of Transition (go vs. no-go trial in  $N - 1$ ), Preceding trial correspondence (corresponding vs. non-corresponding), and current trial correspondence (corresponding vs. non-corresponding trial). Since significant and nonsignificant effects of Correspondence in both the joint and in the individual tasks were confirmed, they are not reported.

In Experiment 1A, the main effect of Transition was significant,  $F(1, 23) = 19.735, p < .001, \eta^2_p = 0.46$ , with faster RTs in trials preceded by a no-go trial (384 ms) than in trials preceded by a go trial (399 ms). This finding is consistent with the use of no-go trials as a cue for predicting the occurrence of the next go trial, this resulting in better response preparation after no-go trials. Neither Preceding trial correspondence,  $F(1, 23) = 1.059, p = .314, \eta^2_p = 0.04$ , nor the interactions involving these factors,  $F_s(1, 23) < 2.5, p_s > .125, \eta^2_{ps} < .09$ , reached significance.

In Experiment 1B, the effect of Transition was significant for the upright stimuli group,  $F(1, 23) = 5.166, p = .033, \eta^2_p = 0.18$  (go <sub>$N-1$</sub>  = 393 ms vs. no-go <sub>$N-1$</sub>  = 387 ms), whereas the upside-down stimuli group showed a nonsignificant effect, even though in the same direction,  $F(1, 23) = 4.136, p = .054, \eta^2_p = 0.15$  (go <sub>$N-1$</sub>  = 422 ms vs. no-go <sub>$N-1$</sub>  = 416 ms). Similarly to Experiment 1A, stimulus repetition or switch was probably used to predict whether it was one's own or the other participant's turn in responding (Liepelt et al., 2011; Liepelt, Wenke, & Fischer, 2013), with better response preparation following the response of the other participant. No other source of significance was observed for upright,  $F_s(1, 23) < 1.3, p_s > 0.274, \eta^2_{ps} < 0.05$ , and for upside down,  $F_s(1, 23) < 3.8, p_s > 0.063, \eta^2_{ps} < 0.14$ , stimuli.

In Experiment 2A, neither the main effect of Preceding trial correspondence,  $F(1, 23) = 1.052, p = .316, \eta^2_p = .04$  and Transition,  $F(1, 23) = 0.304, p = .587, \eta^2_p = .01$ , nor the interactions involving the two factors,  $F_s(1, 23) < 1.3, p_s > 0.256, \eta^2_{ps} < 0.06$ , reached significance.

In Experiment 2B, the upside-down stimuli group displayed a significant Transition  $\times$  Current trial correspondence interaction,  $F(1, 23) = 5.805, p = .024, \eta^2_p = .20$ , with a significant correspondence effect in trials preceded by a go trial (382 vs. 393 ms),  $t(23) = 3.971, p = .001, d_z = 0.90$ , but not in trials preceded by a no-go trial (382 vs. 386 ms),  $t(23) = 1.603, p = .123, d_z = 0.33$ . Furthermore, a significant Transition  $\times$  Preceding trial correspondence  $\times$  Current trial correspondence interaction was observed for both the upright,  $F(1, 23) = 6.352, p = .019, \eta^2_p = .22$ , and the upside-down stimuli groups,  $F(1, 23) = 5.229, p = .032, \eta^2_p = .18$ . In both the groups, the correspondence effect was significant in trials preceded by a go corresponding trial,  $t_s(23) < 4.1, p_s < 0.004, d_{zs} > 0.65$ , but not in trials preceded by a go non-corresponding trial,  $t_s(23) < 1.4, p_s > 0.186, d_{zs} > 0.18$ . Furthermore, the correspondence effect was not significant in trials preceded by a no-go corresponding trial,  $t_s(23) < 0.4, p_s > 0.681, d_{zs} > 0.03$ , and in trials preceded by a no-go non-corresponding trial,  $t_s(23) < 2.5, p_s > 0.023, d_{zs} > 0.38$  (corrected  $p$  level = 0.01). No other sources of significance were found,  $F_s(1, 23) < 1.5$  (see Table 3).

**Table 3** Mean RTs for corresponding (C), non-corresponding (NC) trials and correspondence effect preceded by go/nogo and corresponding ( $C_{N-1}$ )/non-corresponding ( $NC_{N-1}$ ) trials for Experiments 1A and 1B, and for Experiments 2A and 2B

	Go/Go						Nogo/Go					
	$C_{N-1}$			$NC_{N-1}$			$C_{N-1}$			$NC_{N-1}$		
	C	NC	Effect	C	NC	Effect	C	NC	Effect	C	NC	Effect
Experiment 1A—upright	395	403	8	398	398	0	385	385	0	384	382	-2
Experiment 1B—upright	385	398	13	388	401	12	382	392	10	382	392	10
Experiment 1B—upside down	417	430	13	418	423	5	407	421	14	413	422	9
Experiment 2A—upright	388	390	2	393	392	-1	389	387	-2	387	391	4
Experiment 2B—upright	372	386	14*	374	377	4	372	373	1	367	377	9
Experiment 2B—upside down	379	397	18*	384	390	6	383	385	2	380	388	8

To summarize, sequential effects due to prior trial nature and prior trial correspondence were observed only in Experiment 2B with both upright and upside-down stimuli. Specifically, the handle-to-hand correspondence effect was significant when the responding participant within the pair also responded in the preceding trial and this response spatially corresponded to the position of the stimulus's handle, whereas it did not reach significance when the participant responded to the preceding non-corresponding trial, and when she/he did not respond in the preceding trials. These results are in line with previous findings in individual two-choice tasks showing a decreased or absent Simon effect following non-corresponding than corresponding trials (Akçay & Hazeltine, 2007; Hommel, Proctor, & Vu, 2004; Iani, Rubichi, Gherri, & Nicoletti, 2009; Iani, Stella, & Rubichi, 2014). They are also consistent with results observed in joint go/no-go tasks reporting a negative Simon effect following non-corresponding trials (Liepelt et al., 2011).

Even though participants performed a joint task, sequential effects were not observed in Experiment 1B. This difference between experiments could be due to stronger bottom-up driven S-R feature bindings (Hommel, 1998) in Experiment 2B as compared to Experiment 1B because in Experiment 2B response locations were closer to stimulus locations relative to Experiment 1B.

Sequential analyses of Experiments 1A and 2A showed no handle-to-hand correspondence effect irrespective of whether the preceding trial was a go or a no-go trial, and of whether it was corresponding or non-corresponding. This last result differs from the sequential effects reported by Liepelt et al. (2011) for an individual go/no-go task. However, it was obtained with different stimulus materials. Indeed in our study, centrally presented pictures of real objects were employed, whereas in Liepelt et al. (2011) lateralized shape stimuli were used. The nature of the spatial codes produced for object stimuli (Pellicano et al., 2017b; Cho & Proctor, 2010) is thought to be different from that of lateralized shape or color stimuli (Baroni, Pellicano, Lugli, Nicoletti, & Proctor, 2012); therefore it might be the case that differences in low-level feature binding mechanisms applied to our stimulus set.

In conclusion, the observed sequential effects seem to be more consistent with the view that basic interactions between stimulus and response codes (Simon-like effect), instead of activation of motor affordances, were the basis of our results.

## General discussion

The handle-to-hand correspondence effect refers to the finding of faster and more accurate responses when the responding hand is aligned with the graspable part of an object tool,

compared to when they lay on opposite sides. The present study was aimed at investigating whether this effect depends on the activation of grasping affordances (affordance activation account) or rather it is due to spatial coding of stimuli and responses, and to their dimensional overlap (location coding account).

According to the affordance activation account, handle-to-hand corresponding responses are faster and more accurate than noncorresponding ones because they best fit with the motor affordance elicited by the object (i.e., a grasping action of the hand aligned with the handle). However, according to the location coding account, the effect depends on the automatic activation of a generic, grasp-unrelated spatial response that is on the same side of the stimulus. Crucially, this automatic response is only activated when there is dimensional overlap between the stimulus spatial code and the response spatial code. Indeed, the location coding account considers the handle-to-hand correspondence effect as a Simon effect for which the spatial value of the stimuli depends on the orientation of their visually salient portion, which correspond to their graspable tips (as they provide asymmetry to the object stimuli).

We tested the assumption that, if the identification of an object brings to the activation of the motor programs that subtend its manipulation (i.e., its proper grasping affordances), the handle-to-hand correspondence effect should emerge irrespective of whether the task requires the emission of a single response (individual go/no-go task), or of two responses (joint go/no-go task). To test this assumption we introduced two manipulations. First, we manipulated the availability of response alternatives by employing unimanual (single effector) go/no-go tasks performed by single participants (i.e., absence of spatial response alternative, Experiment 1A and 2A), and by pairs of participants (i.e., two spatial response alternatives, Experiment 1B and 2B). Indeed, our study utilized the availability of response alternatives, as well as their absence, to discriminate between the affordance activation account and the location coding account. Second, we employed different response modes: a button-press response in Experiments 1A and 1B, as for most of previous investigations on handle-to-hand correspondence effect (see Proctor & Miles, 2014), and a precision grasp action in Experiments 2A and 2B. This response type was introduced to increase the possibility that motor affordances could be evoked (Bub & Masson, 2010; Bub et al., 2018; Couth, Gowen, & Poliakoff, 2014; Iani et al., 2011).

We found no handle-to-hand correspondence effect in the individual go/no-go version of the task either when a button-press response (Experiment 1A) or a grasping (Experiment 2A) response was required. A significant handle-to-hand correspondence effect, however, emerged when the task was performed by pairs of participants sitting alongside each other (Experiments 1B and 2B). Taken together, these results

do not support the idea that motor affordances are automatically activated for meaningful objects: unimanual responses did not benefit from these activations even if handle-to-hand alignment and non-alignment conditions were provided for the employed single effector. This negative evidence was made stronger by the results of Experiment 2A showing that even when the required response was more similar to the grasping gesture to be afforded by the handle orientation, no sign of an affordance effect was observed. Distribution analyses of RTs displayed that the correspondence effect in Experiment 1A and 2A stayed nonsignificant across the whole RTs distribution, thus ruling out the possibility that full activation of affordances was slower and needed more time to be observed. To note, the size and the time course of the handle-to-hand correspondence effect observed in the joint go/no-go Experiment 1B and 2B were similar to those observed in individual choice-reaction experiments that employed the same stimulus materials (Riggio et al., 2008). This suggests, in light of the most recent investigations (see Pellicano et al., 2017b), that similar stimulus–response coding mechanisms took place in the present joint go/no-go experiments relative to previous individual choice-reaction ones. Furthermore, trial-to-trial sequential analyses for Experiments 1A and 2A showed no significant correspondence effect depending on previous trial correspondence and previous go/nogo requirements, thus suggesting that motor affordances were never activated in our go-nogo conditions employing centrally presented object stimuli (but see Liepelt et al., 2011 for significant sequential effects with lateralized shape stimuli).

These results are also relevant in light of four features of our experiments supposed to favor the activation of motor affordances (see Borghi & Riggio, 2015; Pappas, 2014). First, in individual go/no-go experiments, upright object stimuli were matched to go trials, as upright, canonical orientation is more plausible to facilitate the activation of grasping affordances compared to upside-down orientation (Riddoch, et al., 1998; Rounis & Humphreys, 2015). Second, it has been shown that the activation of affordances depends on the amount of realistic visual information consistent with what is encountered in the natural environment. More precisely, affordance effects have been found when detailed photographs of objects were employed but not when 2D silhouettes of the same stimuli were presented (Pappas, 2014). Third, previous studies have shown that the activation of affordances depends on the task. Indeed, affordance effects have been shown only when the task required deep processing of the object characteristics (e.g., shape processing), while they were absent if superficial processing (e.g., color processing) was required (Tipper, Paul, & Hayes, 2006; Pellicano et al., 2010b). Fourth, it has been displayed that the activation of affordances is modulated by the context. Indeed, affordances

are only activated when object stimuli are located in the near peripersonal, but not in the far extrapersonal space (Costantini et al., 2010).

Consistent with these findings, our four experiments employed ecologically valid pictures of kitchen objects, implemented a vertical-orientation discrimination task for which a deeper processing was required and displayed the stimuli within the peripersonal space. The second and fourth point were even more relevant for Experiments 2A and 2B in which the hand mimicking the grasping gesture was held a few centimeters close to the realistic object picture. Notwithstanding these manipulations, no evidence supporting the affordance activation account was found.

Rather, our results are consistent with the more parsimonious location coding account that considers the handle-to-hand correspondence effect as a Simon-like effect (Cho & Proctor, 2010). Indeed, the results of the present study suggest that asymmetries in the structure of our stimuli generated spatial codes which overlapped with the spatial codes formed in the joint go/no-go tasks to discriminate between the two response alternatives (emitted by the two participants). This is consistent with the response discrimination account of the Simon effect (Ansorge & Wühr, 2004) and with one of the most recent accounts of the joint Simon effect, that is, the referential coding account (Dolk et al., 2013; 2014). Because of this dimensional overlap, the spatial orientation of the handle (i.e., the visually salient tip of the object) automatically activated corresponding, grasping-unrelated responses that facilitated and interfered with performance in handle-to-hand corresponding and noncorresponding trials, respectively. This generated a Simon-like effect similar to the one previously observed with other stimuli conveying spatial information when centrally presented, as for example: pointing arrows (e.g., Iani, Ricci, Baroni, & Rubichi, 2009; Masaki, Takasawa, & Yamazaki, 2000; Pellicano, Lugli, Baroni & Nicoletti, 2009; Ricciardelli, Bonfiglioli, Iani, Rubichi, & Nicoletti, 2007), spatial words (e.g., Pellicano et al., 2009) or gazing eyes (e.g., Ricciardelli et al., 2007; Ristic & Kingstone, 2006).

Crucially and consistent with previous studies, when only one response had to be emitted (individual go/no-go tasks), there was no need to spatially code it, and ultimately no Simon-like effect was observed (Dolk et al., 2013; 2014; Prinz, 2015; Dolk & Prinz, 2016).

In conclusion, the present study provided further support to the location coding account of the handle-to-hand correspondence effect through an approach based on availability of response alternatives. Beyond the manipulations reported above, future studies should investigate further aspects supposed to increase the chances for affordance activations; namely: the nature of the stimuli (real objects) combined with appropriate real actions (grasp, or reach-and-grasp actions).

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## Compliance with ethical standards

**Conflict of interest** A. P. declares that he has no conflict of interest. L. L. declares that she has no conflict of interest. F. B. declares that he has no conflict of interest. S. R. declares that he has no conflict of interest. C. I. declares that she has no conflict of interest. R. N. declares that he has no conflict of interest.

**Ethical approval** 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.

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

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