

Handle-Hand Compatibility Effects for the Right and Left Hand Using Reach-to-Touch Movements

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ABSTRACT

In stimulus-response compatibility tasks, performance is better when the handle of an object is oriented on the same side of the response than when the handle is oriented on the opposite side. Two major alternative accounts, the motor affordance and spatial accounts, have been proposed to explain this handle-hand compatibility effect. In two experiments, we tested between these two accounts by administering a go/no-go task to right-handed participants. Handled objects presented on a touchscreen were used as stimuli. Half of the participants had to reach-to-touch the stimuli by using their dominant hand, the other half by using their nondominant hand. Lift-off times (LTs), movement times (MTs) and spatial coordinates of the movement endpoints were recorded. Results from the LTs and MTs analyses showed no evidence of handle-hand compatibility effects. In contrast, the analyses of the spatial coordinates revealed that participants' touches were shifted more laterally towards the handle when the handles were oriented on the same side of the responding hand (Experiments 1 and 2). Furthermore, the right-hand touches landed higher (towards the handle) than the left-hand touches, especially when the vertical object dimension was particularly salient (Experiment 1). Overall, these results are in line with the activation of hand motor programs to reach and grasp the object as predicted by the motor account, at least for the right/dominant hand.

KEYWORDS

handle-hand compatibility
affordance
spatial coding
go/no-go task

INTRODUCTION

Contemporary theories (Ellis & Tucker, 2000; Masson et al., 2011; Thill et al., 2013) refer to affordances (Gibson, 1979) as specific action components resulting from the conjunction of visual and motor experiences in the brain. Hence, the mere observation of objects activates their respective affordances, that is, components of interactive motor programs such as reaching and grasping. The handle is the part of an object specialized for interaction, and various studies provide evidence of its importance in activating motor programs (e.g., Bub et al., 2018; Masson et al., 2011; Tucker & Ellis, 1998). Many of these studies have used spatial stimulus-response compatibility (SRC) tasks. In a typical SRC task, responses are faster and more accurate when the response is

on the same side of the stimulus location, even if the stimulus location is task-irrelevant, as in the Simon task (the so-called Simon effect, SE; Simon, 1969). A Simon-like task has been adopted with everyday handled objects (e.g., Bub & Masson, 2010; McBride, et al., 2012; Pellicano et al., 2010; Tucker & Ellis, 1998). In this case, participants are usually asked to press either a left or a right key to discriminate a general object feature (e.g., upright/downright orientation, identity, colour) presented centrally with their handle oriented to the left or to the right.

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These studies show a handle-hand (H-H) compatibility effect. That is, participants' performance is better when the handle and the correct response are on the same side (compatible condition) than when they are on opposite sides (incompatible condition). According to the motor affordance account, seeing, for example, a coffee cup with its handle to the right or to the left elicits a reaching movement with the right or left effector in order to grasp the cup, with the resultant facilitation of the responses ipsilateral to the handle, and hence, determining the H-H compatibility effects (McBride et al., 2012). However, the H-H compatibility effect has also been explained as resulting from spatial mechanisms (Cho & Proctor, 2010, 2013; Pellicano et al., 2017) similar to those proposed for the classical SE (Kornblum et al., 1990).

There is a general consensus that the SE depends on response-selection processes of two parallel and independent routes, the conditional and unconditional route (De Jong et al., 1994; Lu & Proctor, 1995). While the conditional route determines the activation of a specific response in accordance with the task instructions, the unconditional route activates the response spatially corresponding with the stimulus, regardless of the instructions. The response is quickly emitted when the response codes of the two routes converge, otherwise there is a conflict that delays the response. Moreover, the activation of the unconditional route depends on the spatial overlapping/similarity between stimuli and responses. In a canonical Simon task, with geometrical shapes presented on the right or on the left of a fixation point, the SE is clearly present with right and left alternative responses (Ansorge & Wühr, 2004; Hommel, 1996). In the go/no-go version of the Simon task, the participant has only to decide to give the response or not, without reference to one specific spatial code. In such a case, no SE emerges since the prerequisites for obtaining the effect are lacking, as other response alternatives are not present and no dimensional stimulus-response overlap is possible (Ansorge & Wühr, 2004; see also Lu & Proctor, 1995).

Concerning the H-H compatibility effect, Anderson, Karavia, and Yamagashi (2002) remarked that the handle renders the object asymmetrical, causing a capture of attention towards the handle itself. This attentional shift would then be responsible for the automatic generation of abstract motor codes associated with the spatial characteristics of objects. In other terms, the H-H compatibility effect would not have been generated by the activation of lateralized reach-to-grasp responses, but rather by the dimensional overlap between the handle and the response spatial codes, determining an object-based SE (spatial coding account, see Cho & Proctor, 2010).

The debate around the explanatory validity of the motor and spatial accounts is still open and fuelled by opposite findings of recent studies manipulating different variables, such as the nature of stimuli (silhouette-like pictures vs. photographs of real objects, Pappas, 2014; Proctor et al., 2017); the type of task (unimanual vs. bimanual discrimination, Cho & Proctor 2010; Tucker & Ellis, 1998) or the type of response (key-presses vs. directed actions (Iani et al., 2011; Pavese & Buxbaum, 2002).

Within this debate, some authors have tried to dissociate the spatial and motor accounts by using go/no-go tasks, that is, tasks in which the SE is traditionally absent, with handled objects. In this regard, Roest et

al. (2016) reported a reversed H-H compatibility effect (Experiment 2), or no effects (Experiment 3), while Pellicano et al. (2018) reported null compatibility effects in both Experiments 1A and 2A, where they manipulated the type of response (button-press or grasping). Overall, results from these two studies are in line with the spatial coding account, as the activation of motor affordances should be independent of the presence of right-left alternative responses. However, in these studies, and in most of the H-H compatibility studies using SRC tasks, subjects were never asked to respond performing an action towards the location of the target object, but only to press the correct key for the target or to reach-to-grasp an object that was different from, and in a different location than the target presented on the screen. Since affordances are relational properties involving a direct interaction between a specific object and an organism, it is possible that when the location of the target object is distinct from the location of the response, affordances are difficult to detect in a simple go/no-go task. This reasoning could explain why previous studies adopting such a task failed in detecting compatibility effects generated by genuine motor activations. In fact, tasks in which a real interaction between the object and the effector is expected provide evidence of motor activation specifically linked to the handle. For instance, Rounis et al. (2018), using kinematic measures, have observed effects of the cup handle on grasp movement execution, even though participants were not explicitly instructed to grasp the handle itself.

In an attempt to isolate the possible motor mechanisms contributing in the generation of H-H compatibility effects while overcoming the limitation of previous studies, in two experiments, we adopted a go/no-go task in which subjects were instructed to react to the target object, presented on a touchscreen, by making a reach-to-touch movement towards it. We used a novel response modality involving a non-predetermined endpoint movement towards the location of the target object. This response modality differs from the response modalities used in previous studies, as it does not require any interaction with objects others than the target object (e.g., grasping devices). Even though this response modality is still a simplification of the real interaction a person would have with a real object, we believe that it nonetheless represents a more direct and ecologically valid attempt to maximize the possibilities of finding evidence of sensorimotor links between the effector and object parts. This response modality allowed us to consider three different dependent measures: lift-off time (LT, i.e., the time from the stimulus onset to the start of the movement), movement time (MT, i.e., the time from when the subjects start the movement to when they touch the object on the screen), and the spatial coordinates of the touches on the touchscreen (X-, Y-coordinates). Moreover, to further stress the motor aspects of our task, we asked half of the right-handed participants to respond with their dominant hand, that is, the hand usually used to interact with graspable objects, and the other half to respond with their nondominant hand.

A number of different predictions can be drawn by applying our version of the go/no-go task to the study of the mechanisms generating the affordance effect. Since a go/no-go task does not provide any dimensional stimulus-response overlap necessary for the emergence

of a SE, the presence of a H-H compatibility effect in the participants' LTs would be an evidence of a motor activation elicited by the object. In addition, the presence of compatibility effects in the participants' MTs and/or in the spatial coordinates of the touches may again be interpreted as favouring the motor account. However, the absence of compatibility effects in LTs and MTs and its presence in the spatial measures of the touches does not exclude other mechanisms related to spatial asymmetries of graspable objects. We might also expect a possible modulation of the parameters of the response linked to the handle location by the dominance versus nondominance of the hand used to respond in the task if motor mechanisms are involved. Finally, it is also possible to predict the absence of any compatibility effect at all. In this last scenario, the present work would provide only an indirect evidence, based on a null effect, which would favour the spatial coding account.

GENERAL METHODS

Participants

Thirty members of the Parma community (23 females, $M_{\text{age}} = 24.5$ years old) volunteered to take part in Experiment 1 and twenty¹ (14 females, $M_{\text{age}} = 27$ years old)—in Experiment 2. All participants were right-handed, as measured by a standard handedness inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. All participants were naïve as to the purpose of the experiment. The experiments were conducted in accordance with the Declaration of Helsinki and all participants gave written informed consent.

Apparatus, Stimuli, and Procedure

The experiments took place in a sound-attenuated and dimly illuminated room. The experimental apparatus consisted of an Elo-Entuitive 42 in. touchscreen monitor connected to a computer running the E-Prime 2.0 software. Screen resolution was set at 1920×1080 . Viewing distance was fixed at 43 cm by using an adjustable head- and chin-rest placed in front of the touch-screen. Eye height was adjusted to the level of fixation. Two different paired objects were used in the experiments (see Figure 1). A coffee pot and a milk jug were used in the Experiment 1, and a cup and a creamer pot in Experiment 2. Both object couples were matched for dimension and orientation. In each experiment, visual stimuli consisted of four grayscale photographs, randomly presented on the screen. Each photograph depicted one of two possible handled objects with its handle oriented to the right or to the left. Each object was included in a 350×350 -pixel matrix. The photographs were presented on the screen so that the center of the object body corresponded to the center of the screen. The dimensions of the objects on the screen are represented in Figure 1.

Considering that, in a pilot experiment, no performance difference was found between the two stimuli used in Experiment 1, LT: $F(1, 22) = 0.007, p = .94$; MT: $F(1, 22) = 2.24, p = .15$; X-coordinates: $F(1, 22) = 0.24, p = .63$; Y-coordinates: $F(1, 22) = 0.22, p = .64$, we chose only one response stimulus to simplify the experimental design. Each trial started when the participants pressed and held down the spacebar key with their index finger. The spacebar was located centrally with respect to the subject's body midline. During the experiment, participants kept the index finger of their response hand approximately in the center of the spacebar, which was aligned with their body midline, the fixation cross, and the center of the object. The inactive hand was kept in a rest-

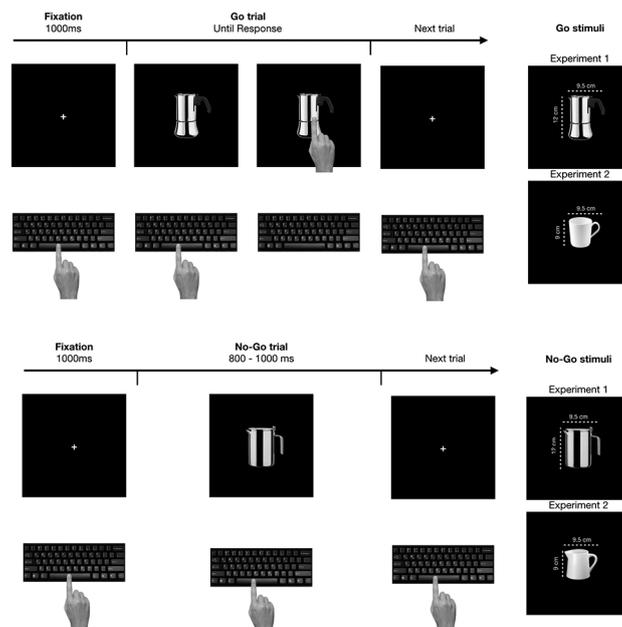


FIGURE 1.

Event sequence in each trial for the go and no-go stimuli. Participants performed a go-no/go task releasing the spacebar and moving to touch the object on the screen. In addition, we reported the real dimension of the objects on the screen.

ing position above participants' knees in a position that was out of their view. After the key press, a fixation cross, on which the participants were instructed to maintain their gaze, appeared at the center of the screen. After 1 s, in both experiments, the fixation cross was replaced by one of the four possible object photographs, which remained on the screen until the participant gave the response. Participants were instructed to respond only to the coffee pot and the cup photographs, and to refrain from responding to the milk-jug and creamer pot, in Experiments 1 and 2, respectively. When the coffee pot or the cup appeared on the screen, the participants had to release the spacebar and make a reach-to-touch movement towards the object on the screen. Here, it is important to note that the instructions given to the participants did not specify which part of the object to be touched. That is, the instructions did not predetermine the response endpoint. After the screen had been touched with the index finger, the object disappeared from the screen and the subjects had to move back their hand and press the spacebar to start the subsequent trial. In contrast, when the milk-jug or the creamer pot appeared on the screen, participants were instructed to keep the spacebar pressed. The milk jug or the creamer pot remained on the screen for a variable time between 800 and 1000 ms. This variable duration allowed the no-go stimulus to stay on the screen for approximately the same time as the go stimulus, measured in the pilot experiment as the sum of the participants' LTs and MTs ($M = 950$ ms). The subsequent trial started with the presentation of the fixation cross. In each experiment, half of the participants responded with the index finger of their right and dominant hand, the other half responded with the index finger of their left and nondominant hand. The experimental task started with a practice session (52 trials). After practice trials, 408 experimental trials were run. Participants were tested individually, and the instructions emphasized the best compromise between speed and accuracy.

Data Analyses

Data analyses were performed using R 3.4.2 (R Core Team, 2017). The participants' LTs (ms), MTs (ms), and X- Y- coordinates of the endpoint of the screen touches (pixels) were recorded and included in the analyses. The LTs were measured from the onset of the object to the start of the movement (i.e., the release of the spacebar). The MTs were defined as the time from the start of the movement to the touching of the object on the screen. Trials in which responses were anticipated (the subject released the spacebar when the fixation cross was still on the screen, or within 150 ms after the stimulus presentation) or incorrect (the subject responded to the no-go object) were excluded from further analyses (45 trials, 0.86 % in Experiment 1 and 53 trials, 1.31% in Experiment 2). Lift-off times slower than 1.5 s were excluded as well (7 trials, 0.12% in Experiment 1; 26 trials, 0.66% in Experiment 2). After that, we selected only the trials in which the touches were included within the object matrix (7 trials discarded, 0.09% from Experiment 1 and 1 trial, 0.03% from Experiment 2). Due to the technology of the touchscreen (Surface Acoustic Wave), occasionally, participants had to touch the screen more than once before the touchscreen recorded the response. This resulted in the recording of artificially slow MTs by E-Prime. For

this reason, we adopted a conservative approach and MTs slower than 1 s were excluded from further analyses, resulting in the total data loss of 17.86% in Experiment 1 and 19.70% in Experiment 2. For all analyses, the α level was set at 0.05.

RESULTS OF EXPERIMENT 1

Lift-off Time and Movement Time Results

The LT and MT distributions were characterized by positive skewness. Two iterative Box-Cox procedures suggested a meaningful $\lambda = -1$ (reciprocal) transformation for both the distributions (for an example of the transformation procedure see Figure 2; Box & Cox, 1964; Klein Entink et al., 2009). Accordingly, all statistical analyses were performed on these transformed data. Transformed data were entered into two different mixed-model analyses of variance (ANOVA) with Compatibility (handle-hand compatibility, handle-hand incompatibility) as a within-subjects factor and Response Hand (right, hand) as a between-subjects factor. Reported means were transformed back to milliseconds by computing the inverse of the Box-Cox transformation. The main effect of Response Hand was not significant, $F(1, 28) = 0.3, p = .6$, with 504 ms for the right and dominant hand and 522ms for the left and non-dominant hand. Similarly, the main effect of Compatibility was not significant, $F(1, 28) = 2.14, p = 0.15$, with 510 ms and 514 ms for compatible and incompatible trials, respectively. Also, the interaction between Compatibility and Response Hand did not reach significance, $F(1, 28) = 0.16, p = 0.7$.

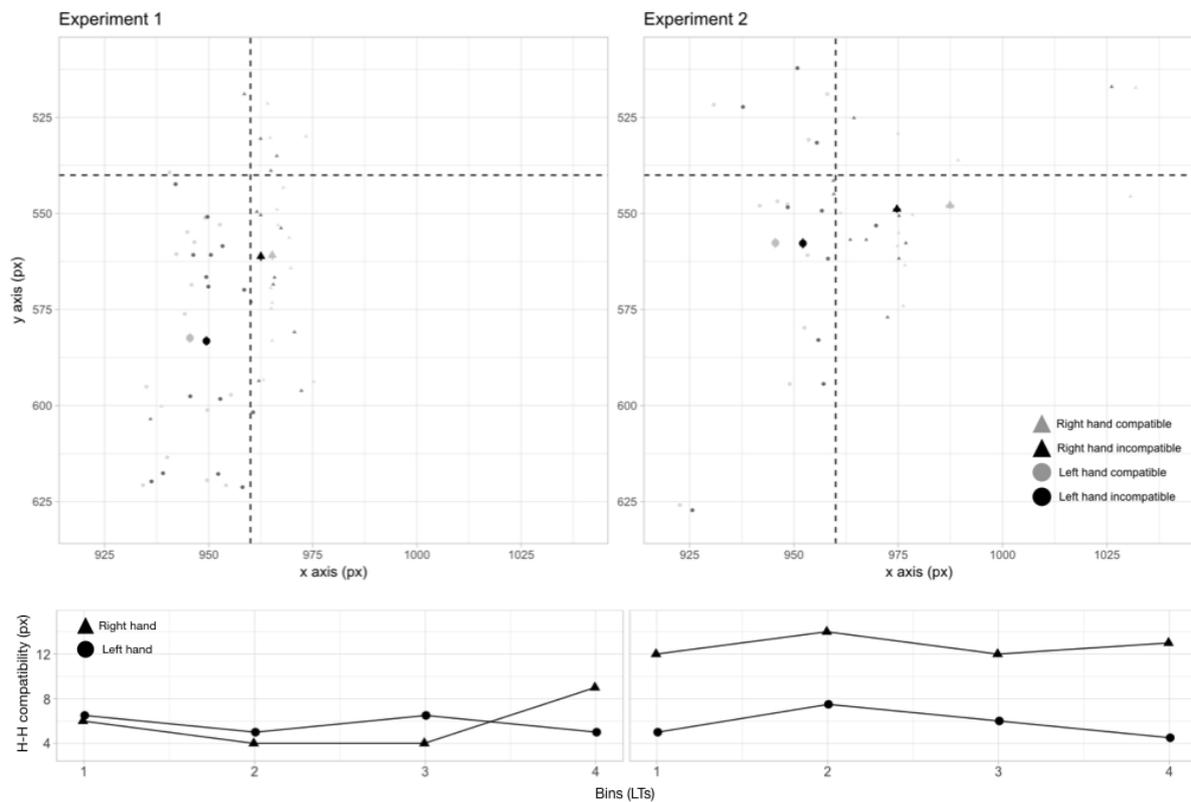
For the MT analysis, neither the main effects nor the interaction reached statistical significance, all $F_s(1, 28) < 1, p_s > .3$. In particular, no difference was found between compatible and incompatible conditions (403 ms in both conditions). All descriptive statistics are reported in Table 1.

X- Y-Coordinates Results

Finally, X- Y-coordinates of the screen touches were analysed using a mixed-model multivariate analysis of variance (MANOVA) with X- and Y-coordinates in pixels as dependent variables. This analysis included the same within- and between-subjects factors considered in the previous analyses.

Results revealed a significant main effect of Response Hand, $V = 0.59, F(1, 28) = 18.53, p < .0001$, while the main effect of Compatibility was not significant, $V = 0.037, F(1, 28) = 0.51, p = .6$. The interaction between Response Hand and Compatibility reached statistical significance, $V = 0.45, F(1, 28) = 10.85, p < .001$.

To better understand the results from the MANOVA, we performed two separate univariate ANOVAs of X- and Y-coordinates. The analysis of Y-coordinates revealed that only the main effect of Response Hand was significant, $F(1, 28) = 4.71, p = .0385, \eta^2_G = .142$. As shown in Figure 2, subjects responding with their dominant/right-hand touched the screen further up ($M = 561$ st px on Y-axis) than subjects responding with their non-dominant/left-hand ($M = 583$ rd px

**FIGURE 2.**

The upper panels show the pattern of the results on the X- and Y-axes for the Experiments 1 and 2. The Y-axis is inverted as the origin of the X- and Y-axis of a screen is placed in the upper-left angle when viewed frontally. Each point represents the mean of the endpoints of the touches for right (circle) and left (triangle) hands. The handle-hand compatible trials are indicated in grey, the handle-hand incompatible trials in black. Error bars represent the associated SEM. Dotted lines identify the midline of the object and the screen. Small dots and triangles in background indicate the participants' means. The results of the time course analyses are reported in the lower panels. The differences of the endpoints of the touches (in pixels), expressed in absolute values, are shown for left hand as circles, and for right hand as triangles, as a function of bins.

on Y-axis). Neither the main effect of compatibility, $F = 0.18$; $p = .67$, nor the interaction, $F = 2.63$, $p = .12$, reached statistical significance.

The analysis on X-coordinates showed a significant main effect of Response Hand, $F(1, 28) = 39.11$, $p < 0.001$, $\eta^2_G = .54$, indicating that each hand touched the object in the ipsilateral hemifield (i.e., right or left hemifield for the right or the left hand; right = 963rd, left = 947rd, see Figure 2). Moreover, the left hand showed a larger shift of the touch towards the ipsilateral part of the screen in comparison to the right one (difference from center: right = 3, left = -13), as represented in Figure 2, left panel. The effect of H-H compatibility was found in the interaction between Response Hand and Compatibility, $F(1, 28) = 20.22$, $p = .001$, $\eta^2_G = .05$, since in the compatible condition the hands landed in opposite directions. Splitting the data according to the response hand and performing the post-hoc pairwise comparisons with the Bonferroni correction showed that the difference between the compatible and incompatible conditions was significant for both hands (right: p -adjusted = .021, left: p -adjusted = .0005; for descriptive statistics see Table 1).

Time Course of Handle-Hand Compatibility Effects

Since the literature highlighted different temporal trends for the Simon and the affordance effects (e.g., Riggio et al., 2008; Iani et al., 2011), we analysed the magnitude of the H-H compatibility as a function of LT. In addition, we tested the compatibility effects of the touches on the X-axis as a function of the LT. For this purpose, we calculated the mean LTs of the untransformed data for the first to fourth quantile (bins) following the Vincentization procedure (Ratcliff, 1979). We performed a mixed-model ANOVA on LTs with Bin and Compatibility as within-subjects factors, and Response Hand as a between-subjects factor. Despite the main effect of Bins, $F(3, 84) = 329.5$, $p < .001$, neither main effects nor the interaction reached statistical significance (all $ps > .15$).

In order to examine the influence of the response speed on the size of the compatibility effect on the X-axis, we used the absolute value of the difference between incompatible and compatible X-coordinates for each bin. This manipulation has been introduced

TABLE 1.

Descriptive Statistics of Lift-off Times, Movement Times, X- and Y-Coordinates of Experiment 1

		Lift-off times			Movement times			X-Coordinates			Y-Coordinates		
		<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>
Right	Compatible	523.0	115.4	3.3	398	165.4	4.7	965	20.1	0.6	560	39.2	1.1
	Incompatible	530.8	129.1	3.6	393	165.5	4.7	962	18.4	0.5	562	39.0	1.1
Left	Compatible	536.7	97.0	2.8	408	164.3	4.7	945	19.9	0.6	582	42.0	1.2
	Incompatible	538.7	99.1	2.8	412	175.0	4.9	949	21.1	0.6	583	41.3	1.2

TABLE 2.

Descriptive Statistics of Lift-off Times, Movement Times, X- and Y-Coordinates of Experiment 2

		Lift-off times			Movement times			X-Coordinates			Y-Coordinates		
		<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>	<i>M</i>	<i>SD</i>	<i>SEM</i>
Right	Compatible	539.9	52.8	16.7	520.9	96.8	30.6	987	28.8	0.9	548	27.4	1.8
	Incompatible	538.6	49.8	15.7	517.4	102.6	32.4	975	25.7	0.8	549	27.7	1.8
Left	Compatible	503.4	52.9	16.7	505.8	67.8	21.4	946	21.9	0.7	558	39.3	2.5
	Incompatible	503.6	66.6	21.1	501.5	65.4	20.7	952	21.3	0.7	558	38.9	2.5

in order to avoid values of opposite sign for the two hands, since the H-H compatibility effects for the two hands had opposite directions. We entered this difference in a new mixed-model ANOVA as a dependent variable, with Response Hand as a between-participants factor and Bin as a within-participants factor. Only the interaction between Response Hand and Bin was significant, $F(3, 84) = 2.75$, $p = .047$, $\eta^2_G = .09$, showing two different time courses of the touches for the two hands. Post-hoc pairwise comparisons with Helmert contrast and Bonferroni correction, after splitting the data according to response hand, revealed that the only significant difference was between the third and fourth bin for the right hand (p -adjusted $< .01$). In particular, for the left hand, the compatibility effect remained relatively constant across the bins (Bin 1 = 6.5, Bin 2 = 5, Bin 3 = 6.5, Bin 4 = 5), while for the right hand (Bin 1 = 6, Bin 2 = 4, Bin 3 = 4, Bin 4 = 9, see Figure 2 – bottom panel) there was a significant increase in the last bin.

RESULTS OF EXPERIMENT 2

Lift-off Time and Movement Time Results

The LT and MT distributions were characterized by positive skewness. Two iterative Box-Cox procedures suggested meaningful $\lambda = -1$ transformation for LTs and $\lambda = -2$ for MTs. Accordingly, all statistical analyses were performed on these transformed data. As in the previous experiment, we performed two mixed-model ANOVAs. Reported means were transformed back to milliseconds by computing the inverse of the Box-Cox transformation. In both ANOVAs, no main effects or interactions were significant. All descriptive statistics are reported in Table 2.

X- Y-Coordinates Results

As before, X- Y-coordinates of the screen touches were analysed using a mixed-model MANOVA with X- and Y-coordinates in pixels as dependent variables. This analysis included the same within- and between-subjects factors considered in the previous analyses.

Results revealed that both the main effects of response hand, $V = 0.44$, $F(1, 18) = 5.87$, $p = .013$, and of compatibility were significant, $V = 0.51$, $F(1, 18) = 7.77$, $p = .005$. Moreover, their interaction was also significant, $V = 0.46$, $F(1, 18) = 7.15$, $p = .006$. As before, separate ANOVAs were carried out on X- and Y-coordinates. For the Y-coordinates, even if the right hand landed higher ($M = 548$) than the left hand ($M = 558$), as in the previous experiment, this difference was not significant, $F = 0.61$, $p = .44$.

For the X-coordinates, the ANOVA showed that both the main effect of Response Hand, $F(1, 18) = 19.04$, $p < .001$, $\eta^2_G = .48$ (reported previously as difference from the center: right = 21, left = -11), and the interaction between response hand and compatibility, $F(1, 18) = 10.21$, $p = .005$, $\eta^2_G = .07$, were significant. Pairwise post-hoc comparisons, with Bonferroni correction, after splitting the data according to the response hand, showed that the compatibility effect reached statistical significance only for the right hand (right: p -adjusted = .006, left: p -adjusted = .190). The main effect of Compatibility was not significant, $F = 1.54$, $p = 0.23$. Descriptive statistics are reported in Table 2 (see also Figure 2, right panel).

Time Course of Handle-Hand Compatibility Effects

As in Experiment 1, we analysed the magnitude of the H-H compatibility on LT and X-coordinates as a function of LT. We performed a new mixed ANOVA on LTs with Bin and Compatibility as within-subjects factors, and Response Hand as a between-subjects factor.

Despite the main effect of Bins, $F(3, 54) = 82.85, p < .001$, neither main effects nor the interaction reached statistical significance, all $ps > .12$. In order to evaluate the effect of the response speed on the magnitude of the H-H compatibility found in X-coordinates, we used the absolute value of the difference between incompatible and compatible X-coordinates for each bin. We entered this difference as a dependent variable in a new mixed-model ANOVA, with Response Hand as a between-subjects factor and Bin as a within-subject factor. The interaction between Hand and Bin was not significant, $F = 0.13, p = .9$. The H-H compatibility effect was relatively constant across bins for both hands (Left: Bin 1 = 5, Bin 2 = 7.5, Bin 3 = 6, Bin 4 = 4.5; Right: Bin 1 = 12, Bin 2 = 14, Bin 3 = 12, Bin 4 = 13; see Figure 2 – Bottom panel).

Experiments Comparison

We checked whether the effects found in the two experiments were comparable. The H-H compatibility effects on X-coordinates detected in Experiments 1 and 2 were entered in an ANOVA with Experiment (Experiment 1, Experiment 2) and Response Hand (right, left) as between-subjects factors. Results revealed that both the Hand effect, $F(1, 46) = 25.98, p < .0001$, and the interaction between Response Hand and Experiment, $F(1, 46) = 6.05, p = .02$, reached statistical significance. Data and post-hoc comparisons highlighted that for the left hand, the H-H compatibility effect was similar in the two experiments (Experiment 1: 4 px; Experiment 2: 6 px; p -adjusted = .58). For the right hand, the effect was significantly greater in Experiment 2 as compared to Experiment 1 (Experiment 1: 3 px; Experiment 2: 12 px; p -adjusted = .005).

Moreover, we tested the overall shift of the two hands. We performed a new ANOVA on X-coordinates with Experiment (1, 2) and Response Hand (right and left). Results revealed the main effects of Experiment, $F(1, 46) = 6.49; p = .014$, and Response Hand, $F(1, 46) = 51.09; p < .0001$. The two main effects become clear in the interaction, $F(1, 46) = 5.13; p = .028$, indicating a difference between the two experiments for the right hand but not for the left hand (see Figure 2).

Concerning the Y-axis, we included the Y-coordinates in a new ANOVA with Experiment (1, 2) and Response Hand (right and left) as between-subjects factors. Both the main effects of Response Hand and Experiment reached statistical significance, $F(1, 46) = 4.59; p = .036$ for Response Hand and $F(1, 46) = 6.07, p = .0176$ for Experiment. The data showed a mean difference about 20 px between experiments (Experiment 1: 572 px; Experiment 2: 553 px) and about 15 px between the two Response Hands (Right 1: 555 px; Left 2: 570 px).

DISCUSSION

The aim of this study was to compare the two major accounts (motor affordance and spatial coding), that have been proposed to explain the H-H compatibility effect, using a novel response modality in a go/no-go task to highlight possible hand-object sensorimotor links. In our task, the participants responded with a reach-to-touch movement to the target object, in which the part of the object to be touched was not

previously defined. Since the spatial coding account does not predict compatibility effects in a go/no-go task, the presence of a H-H compatibility effect should be interpreted in favour of the motor affordance account. More specifically, we reasoned that if the H-H compatibility effect is generated by an activation of hand motor program, it should be present in at least one or more of the participants' response measures (LTs, MTs, X-Y-coordinates). Moreover, we predicted a modulation of a motor activated effect by the dominance condition of the hand used to respond.

In line with Roest et al. (2016) and Pellicano et al. (2018), as well as with the classic SE literature, our analyses failed to reveal any significant H-H compatibility effect in the participants' LTs and MTs in both experiments. In contrast, the analyses on the spatial coordinates indicated that the endpoints of reach-to-touch movements are affected by three components that interact with each other: the response hand, the position of the handle in relation to the object body, and the handle orientation. As regards to the response hand, in both experiments, the touches of each hand landed in its respective ipsilateral space, but while the left-hand touches remained relatively constant between the two experiments, the right hand touches appear to be affected by the position of the handle in relation to the object body. Specifically, in Experiment 1, when the coffee pot was the target object (i.e., the handle was above the horizontal midline of the object), the vertical axis seemed to acquire greater weight as compared to the horizontal axis. In contrast, in Experiment 2, right hand touches were shifted more laterally, which also seems a reflection of the position of the handle relative to the cup body (i.e., the handle partly extended also below the horizontal midline of the object). Regarding the orientation of the handle, we detected a greater horizontal (X-coordinates) shift of the touches towards the handle location for both hands when the handle orientation was compatible with the response hand, that is, when the right or the left hand responded to a target with the handle oriented to the right or to the left. As above, when the vertical dimension was less pronounced, as for the cup, the magnitude of H-H compatibility effect was greater for the right hand in comparison to the left hand, but also to the overall H-H compatibility effect of the right hand in Experiment 1. Furthermore, for the Y-coordinates, in both experiments, right-hand touches were localized further up, closer to the handle location, in comparison to left-hand touches. The reason that this difference reaches the conventional level of significance only in Experiment 1 is probably due, as previously discussed, to the higher location of the handle in relation to the body of the object in this experiment (see Figure 1).

To sum up, right-hand touches seem to be more clearly affected by the location of the handle, with higher landing positions and more lateral shifts of the touches (Experiment 2), and greater H-H compatibility effects (as overall compatibility effect in Experiment 2 or as larger effect associated with longer LTs in Experiment 1) in comparison to left hand touches, which remain relatively constant between the two experiments.

Effects related to an object handle position with respect to the response (right) hand have been reported in a go/no-go task using kinematic measures, that is, when variables reflecting parameters of the

hand-object interaction are evaluated. De Stefani et al. (2014, see also Rounis et al., 2018) demonstrated modifications of the maximal finger aperture of pantomimed reaching - grasping of the right hand towards the handle, but only when the object (cup) was located at reachable distance. When the handle was on the right side, congruent with the pantomime, there was a decrease in maximal finger aperture, while when it was incongruent (on the left side), there was an increase, probably because in this case, the cup body was closer to the grasping hand. In our study, only the spatial coordinates of the touches showed clear compatibility effects driven by the handle location. This result alone does not allow us to exclude other non-motor explanations. In fact, the target object was presented with the body centered on the screen, and the handle protruding to the right or to left. One might assume that participants aimed for the center of the entire object and, therefore, that touches should be generally shifted toward the side of the handle. In principle, such a claim might explain the interaction between compatibility and response hand for the X-coordinates, since in the compatible trials, the endpoints of the touches were more lateralized than in incompatible trials. However, this hypothesis cannot explain the differences of the compatibility effects between the two hands. Also, it cannot explain the difference of the endpoints of the touches in the vertical coordinates, as mentioned previously. These differences between the two hands may be related to the preferential use of the right/dominant hand to reach and grasp objects, reflecting its specific role with objects.

If, on the one hand, these results, taken together, are consistent with the motor affordance account, on the other hand, they show that, in a go/no-go task, compatibility effects seem detectable when measures concerning components of the actual interaction with the target are adopted. Pavese and Buxbaum (2002) have examined the effect of different response tasks in three experiments. They tested the interference effects caused by handled object distractors presented to the left or to the right of the target object, with a simple button press response or with a reach-to-grasp and a reach-to-point response. Participants had to respond to the colour of the objects with or without handles. The authors found that different patterns of interference affected response modalities. In the button press condition, the interference was driven both by response congruency (e.g., when the target and the distractors were associated with different button-press responses, the interference effect was greater as compared to when the target and the distractors were associated with the same response), and by perceptual salience (e.g., proximity of the handle to initial visual fixation). When the task required the participant to act upon the object (grasping or pointing), the interference was driven by either handle orientation (Experiment 1) or by handle presence (Experiment 2), independently of whether the intended action was pointing or grasping.

Considering the different pattern of results between the two hands, converging evidence was obtained in Janyan and Slavcheva's (2012). In this study, different patterns of H-H compatibility effects for the two hands, in crossed or uncrossed positions, were found. A major finding was that for the right (dominant) hand, the H-H compatibility effect was obtained only when the hand was in an anatomical (uncrossed) position,

in contrast to the left hand, in which the compatibility effect was present both in uncrossed and crossed hands modalities. The authors concluded that these results support the view of activation of motor information for the right hand, in line with evidence that the right/dominant hand has an advantage in interfacing with objects in many aspects of motor behaviour (e.g., Hughes et al., 2011). Asymmetry in the H-H compatibility effect was also revealed by Fischer and Dahl (2007) using a dynamic H-H compatibility task. In their study, participants had to discriminate between two colours of the fixation point, pressing either a left or a right button. In the background, a rotating cup, irrelevant to the task, was presented continuously. Results revealed a H-H compatibility effect that changed continuously in relation to the position of the handle, but one that emerged faster and was longer-lasting for the right hand. Riddoch et al. (1998) also reported a dissociation between the two hands in a patient who had "anarchic hand" behavior when she interacted with objects. She was required to pick up (or point to) left-side cups with the left hand and right-side cups with the right hand, regardless of the handle orientation. When the position of the handle was congruent with the opposite effector, the patient tended to grasp and pick up the cup using the hand associated with the handle position. This interference was apparent for the left hand only when it had to point to the cup, showing a stronger link for the right hand and overlearned responses to a familiar stimulus.

Nevertheless, it remains an open question whether the H-H compatibility effect observed here with the left hand should be linked to the activation of interactive hand programs or whether it might simply arise from differences in the spatial presentation of the objects. In favour of the claim that there are different mechanisms for the compatibility effects of the two hands is the fact that the compatibility effect for the left hand tended to be smaller than the effect for the right hand in Experiment 2 and that their time courses differed in Experiment 1. Indeed, the right hand shows either an overall larger compatibility effect or a larger effect associated with longer LTs in the X-coordinates. This last result could be in line with other affordance studies that found an increase of the H-H compatibility effect in slower response times. This is possibly related to the recruitment of object-based representations (e.g., Symes et al., 2005, Iani et al. 2011). In contrast, the left hand had relatively constant compatibility effects in and between the two experiments. The notion that both motor and spatial information can play a role in spatial compatibility tasks with graspable objects is not a novel one (see Janyan & Slavcheva, 2012; Riggio et al., 2008; Saccone et al., 2016; Symes, et al., 2005), which suggests that the H-H compatibility cannot be reduced to a simple object-based SE, and that a complex interplay of spatial and motor mechanisms may be involved.

Thus, our suggestion is that the modulatory effects of the handle location both on the X- and Y-coordinates demonstrate an activation of hand motor programs in order to reach and grasp the object, as predicted by the motor account, at least for the dominant hand. In conclusion, it seems that the explanatory power of the motor and spatial accounts for H-H compatibility may depend on both the specific task that is used and the performance measures that are recorded.

FOOTNOTES

¹ Sample size of Experiment 2 was defined using the MANOVA Pillai trace of the interaction of Experiment 1 and calculated with G*Power 3.1. The parameters adopted are: $V = 0.46$, $\alpha = 0.05$, $\beta = .095$. The analysis showed a critical $F = 4.45$ with an expected sample size of 19 participants.

² For both experiments, we repeated the same analyses on all dependent variables with a less conservative approach (MTs < 1.5 s, Experiment 1 lost data = 8.48%; Experiment 2 lost data = 5.98%). The analyses showed the same pattern of results. No statistical difference was found in LTs and MTs; in the XY coordinates the MANOVA showed a main effect of hand, $V_{\text{exp1}} = 0.61$, $F(1, 28) = 19.81$, $p < .001$; $V_{\text{exp2}} = 0.42$, $F(1, 18) = 5.33$, $p = .018$, and the interaction between hand and compatibility was also significant, $V_{\text{exp1}} = 0.41$, $F(1,28) < 9.45$, $p = .001$; $V_{\text{exp2}} = 0.42$, $F(1, 18) = 6.21$, $p = .009$. Moreover, the main effect of compatibility was also significant for Experiment 2, $V_{\text{exp2}} = 0.45$, $F(1, 18) = 6.06$, $p = .012$. Technical specifications of the touchscreen describe the accuracy in recording the position of the touch as less than 1% error, equivalent to less than 0.203 mm (i.e., less than 1 px since the size of 1 px is about 0.4 mm).

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