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On the relationship between affordance and Simon effects: Are the effects really independent?

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The aim of the present study was to investigate the relationship between the affordance effect (i.e., the advantage for responses corresponding spatially with the location of an object's graspable part) and the Simon effect (i.e., the advantage for responses corresponding spatially with stimulus location) and to assess whether they both occur at the response selection stage. In two experiments participants were required to respond according to the vertical orientation (upward or inverted) of photographs of graspable objects, located to the left or right of fixation, with their handles oriented to the right or left. In Experiment 1 the response was a buttonpress; in Experiment 2 was a reaching movement. Our results showed that both Simon and affordance effects emerged in response times but not in movement times. In Experiment 1, the two effects did not interact, whereas a clear interaction emerged in Experiment 2. These results seem to suggest that the interaction between Simon and affordance effects may depend on the type of required action.

Keywords: Affordance effect; Motor control; Response selection; Simon effect.

There is increasing empirical evidence suggesting that perception and action are not separate processes but rather that visual information about objects is processed in an action-dependent way. This means that perceiving an object involves not only the representation of information on its identity, but also of information on the set of potential actions it affords (Cisek, 2001, 2007). As suggested by Hommel and colleagues, the direct link between perception and action may be possible because these representations may be stored in a common representational space (Hommel, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990).

Supporting the view of a connection between perception and action are the results of several studies showing that the appearance of an object automatically activates a series of actions congruent with some of its visual properties such as location, orientation, and the orientation of eventual graspable parts. Importantly, these features seem to guide our interactions with objects even when they are not useful for reaching the current goals. As regards stimulus location, it has been shown that, when participants are required to make a lateralised response to a nonspatial stimulus feature, motor responses are faster and more accurate when the location of the stimulus corresponds to the location of the required response, despite the fact that target location is completely irrelevant for performing the task (Simon & Rudell, 1967; for a review see Proctor & Vu, 2006). This phenomenon, known as the Simon effect, is considered as a response selection

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phenomenon (e.g., de Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Rubichi & Pellicano, 2004; Valle-Inclán, 1996) and has been taken as a clear indication that stimulus location is automatically coded and primes the corresponding response (e.g., Kornblum et al., 1990; for a review see Hommel & Prinz, 1997). When the automatically activated response is the same as the response indicated by task instruction, as occurs in corresponding trials, performance is fast and accurate. In contrast, when the two responses do not correspond, as in noncorresponding trials, the automatically activated response has to be blocked before the correct one can be executed. As a consequence, performance is slower and more error-prone.

Tucker and Ellis (1998, 2001) observed that, when participants were required to make button-press responses with the left or right hand to the vertical orientation (upright or inverted) of a centrally presented graspable object, responses were faster when the graspable part corresponded spatially with the required response. More precisely, if participants were required to respond with the right hand to upright objects and with the left hand to inverted objects, response times were faster when the graspable part of the upright object was on the right (corresponding trial) compared to when it was on the left (noncorresponding trial). This advantage for corresponding trials (from now on, affordance effect) has been interpreted as an indication that the location of the graspable part of an object automatically affords a motor programme.[1]

Given the apparent similarity between the Simon and affordance effects (see Michaels, 1988, for an affordance interpretation of the Simon effect), some studies have tried to compare them directly. By simultaneously manipulating the visual location of objects and the location of their graspable parts within the same paradigm, Symes, Ellis, and Tucker (2005) found that the separate codes formed for object location and for the location of the object's graspable part produced distinct compatibility effects. The lack of an interaction between the two effects, as well as their different time courses (Phillips & Ward, 2002), seems to suggest that the affordance and Simon effects are independent and exert additive effects on performance.

To note, the idea of an independence between the two effects is brought into question by two observations. First, the affordance effect tends to be larger when the Simon effect cannot arise because of the way stimuli and/or responses are arranged. More precisely, it is larger when objects are presented centrally (e.g., Tucker & Ellis, 1998) or when stimulus position and response position do not share the same spatial coding, for example, when stimuli presented above and below fixation require a left–right response compared to when stimuli presented left or right of fixation require a left–right response (Riggio et al., 2008). Second, the data by Symes et al. (2005) suggest that the Simon effect tends to be smaller when a significant affordance effect is evident. Taken together, these data seem to be more indicative of an interdependence than of an independence between the two effects, with the congruency between stimulus and response position modulating the influence exerted by the location of the object's graspable part and vice versa.

In the present study we further explored the relationship between the two effects. According to the Additive Factor Logic (Sternberg, 1969), the lack of an interaction between Simon and affordance effects suggests that they affect different processing stages. Given the widespread belief that the Simon effect arises at the response selection stage (e.g., Kornblum, 1992, 1994; Rubichi & Pellicano, 2004), it is plausible to believe that the orientation of the object graspable part affects response execution. To this end, we adapted the paradigm previously used by Rubichi and Pellicano (2004) and measured response time (RT) as an indication of response selection and planning, and movement time (MT), as a measure of response execution (Keele, 1986; Rosenbaum, 1991). If the two effects affect different processing stages they should not interact. Furthermore, the emergence of the affordance effect in MTs would indicate that, differently from the Simon effect, it arises at the response execution stage.

In two experiments, participants were required to respond according to the vertical orientation (upward or inverted) of photographs of graspable objects. Stimuli were shown to the left or to the right of fixation in order to manipulate the correspondence between stimulus location and

[1]To note, our use of the term "affordance" slightly departs from Gibson's use (1979). Indeed, according to Gibson, affordances are properties of the environment taken with reference to the behaving animal. As such, affordances are not ascribed to objects on the basis of perception or by virtue of representation; they are simply perceived. Differently, in line with the concept of microaffordances introduced by Ellis and Tucker (2000), we refer to those object properties whose representation affords a specific action.

response location (Simon effect). Stimuli were also shown with their graspable parts (handles) oriented to the right or to the left to manipulate the correspondence between the position of the stimulus graspable part and response location (affordance effect). Both stimulus location and the position of the object's graspable part were irrelevant to task performance. Participants started the trial with both index fingers holding down two response keys and, according to stimulus vertical orientation (upright or inverted), they were required to lift one of two fingers (RT) and move it to a goal position (MT).

Crucially, in the studies reported earlier, which required a buttonpress response, the affordance effect was rather small in magnitude and it could have been too small to detect an interaction. However, it is possible that the influence of the affordance effect emerges clearly when the response is more similar to the action normally performed to interact with objects. There are indeed studies showing that the planning of a specific action, such as pressing a button, grasping, or pointing, determines the amount of interference exerted by different affordances for action (Pavese & Buxbaum, 2002) and even primes the processing of stimulus features related to that action (Fagioli, Hommel, & Schubotz, 2007). To test this possibility, we manipulated the type of response required to the participants. In Experiment 1 the goal position was represented by a lateral button located to the right for the right index finger and to the left for the left index finger. In Experiment 2, to render the response more similar to a reaching movement, the goal location was represented by a rectangular area on the same touchscreen where stimuli were presented. Since there are indications that the two effects have a different time course, we analysed the magnitude of the effects as a function of response speed using the distributional analysis procedure (de Jong et al., 1994; Ratcliff, 1979).

EXPERIMENT 1

In the present experiment participants were required to release one of two response keys according to the vertical orientation of a graspable object and execute a movement towards a lateralised button. For half of the participants the object disappeared on movement initiation; for the other half it remained visible even after movement initiation. Consistently with previous investigations, we expected to find a Simon effect in reaction times (RTs) but not in movement times (MTs) (Rubichi & Pellicano, 2004).

As regards the affordance effect, we hypothesised that if the effect influences response execution processes, Simon and affordance effects should not interact and the latter should be evident in MTs. Furthermore, the location of the object's graspable part should have a stronger effect if the object remains visible during movement execution. In contrast, the presence of the effect in RTs only would indicate that the effect influences only the processes taken place before the execution of a response.

Method

Participants. Thirty-two undergraduate students of the University of Bologna (25 females) aged 18–26 years volunteered to take part in this experiment for class credit. All were right-handed, had normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment.

Apparatus and stimuli. The experiment took place in a sound-attenuated and dimly illuminated room. Participants sat in front of a 17-inch VGA monitor controlled by a PC computer with their head positioned in an adjustable head-and-chin rest. The distance between the eyes and the screen was about 48 cm and eye height was adjusted to the level of fixation.

Stimuli presentation and response collection was controlled by the E-Prime software system (Schneider, Eschman, & Zuccolotto, 2002). The stimuli consisted of a series of photographs of four kitchen objects with a graspable handle (a coffee pot, a milk jug, a tea-cup, and a beer mug). Each object covered a $5^\circ \times 5^\circ$ area and was displayed 7.76° (centre to centre) to the left or to the right of the white fixation cross ($1^\circ \times 1^\circ$), shown at the centre of the screen. All objects were photographed in greyscale on a black background, in two possible horizontal orientations, one compatible with a right-hand grasp (i.e., handle on the right) and one compatible with a left-hand grasp (i.e., handle on the left), and in two vertical orientations (upward and inverted). The E-Prime response box served for RT and MT acquisition. The two lateral buttons of the response box served for the RT. In order to have enough movement amplitude, two external pads were plugged into the response box and were used for the MT. They were attached to the response box, one at the left and one at the right, at the same distance (4 cm) from the two lateral buttons. The distance between the external pads was 25 cm (centre to centre). The response box was located centrally with respect to the body midline.

Procedure. Participants had to hold down the two response box buttons with their left and right index fingers to start the trial. The beginning of the trial was signalled by the appearance of a fixation cross in the centre of the screen, which remained visible throughout the trial. In each trial a warning tone (100 ms in duration) was delivered. Subsequently, after 1000 ms, the stimulus was presented either to the left or to the right of fixation for 1500 ms. Participants were instructed to respond to the orientation (upward or inverted) of the object. The response consisted in first releasing one of the two lateralised buttons and then reaching and pressing with the same hand one of the two external pads. Instructions emphasised both speed and accuracy.

Reaction time (RT) was measured from stimulus onset to the release of one of the two response box buttons. Movement time (MT) was measured from the release of one of the two buttons to the pressing of the ipsilateral lateralised pad. Half of the subjects used the right-side button-pad for the upward objects and the left-side button-pad for the inverted objects; the other half had the reversed assignment.

For half of the participants, the stimulus disappeared from the display when the response key was lifted (“offset” condition); for the other half it remained visible until completion of the goal movement or until 1500 ms had elapsed (“permanence” condition). Participants were randomly assigned to one of the two conditions.

At the end of each trial participants were informed about RT and accuracy through feedback shown below the fixation cross, followed by a 1000 ms intertrial interval. Participants received an error feedback when they released the response keys before the appearance of the stimulus (anticipations), when the RT was above 1500 ms or when the MT was above 500 ms (delayed responses), when they released the wrong key (response errors), or pressed the wrong lateral button (movement errors).

Participants were tested individually in a single session, which comprised 32 practice trials followed by five blocks of 64 trials each (for a total of 320 trials). An equal number of trials was provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (leftward vs. rightward), and stimulus position (left vs. right of fixation).

Results

Practice trials, as well as trials with RTs faster than 150 ms (1.1%) were excluded from the analyses.

For each trial, we determined both Simon correspondence (i.e., correspondence between stimulus position and response position) and affordance correspondence (i.e., correspondence between handle position and response position). In order to evaluate the time course of the Simon and affordance effects, we ran a distributional analysis (de Jong et al., 1994; Ratcliff, 1979). Correct mean RTs and MTs were computed from the first to the fifth bin of the individual rank-ordered raw data separately for each condition (“offset” vs. “permanence”), Simon correspondence (corresponding vs. noncorresponding), and affordance correspondence (corresponding vs. noncorresponding).

Correct RTs and MTs were then entered into two separate repeated-measures analyses of variance (ANOVA) with Simon correspondence, affordance correspondence, and bin as within-subject factors and condition (offset vs. permanence) as between-subjects factor. When necessary, comparisons were performed using Bonferroni’s test for multiple comparisons.

Mean RTs and MTs and percentage errors as a function of Simon and affordance correspondence are reported in Table 1.

TABLE 1
Mean reaction time (RT) and mean movement time (MT) in Experiment 1 as a function of Simon and affordance correspondence (error percentages in parentheses)

	Affordance			
	Corresponding		*Noncorresponding*	
Simon	*RT*	*MT*	*RT*	*MT*
Corresponding	508 (7.7)	292 (1.1)	520 (8.2)	291 (0.9)
Noncorresponding	560 (16.1)	286 (0.9)	566 (17.5)	286 (1.0)

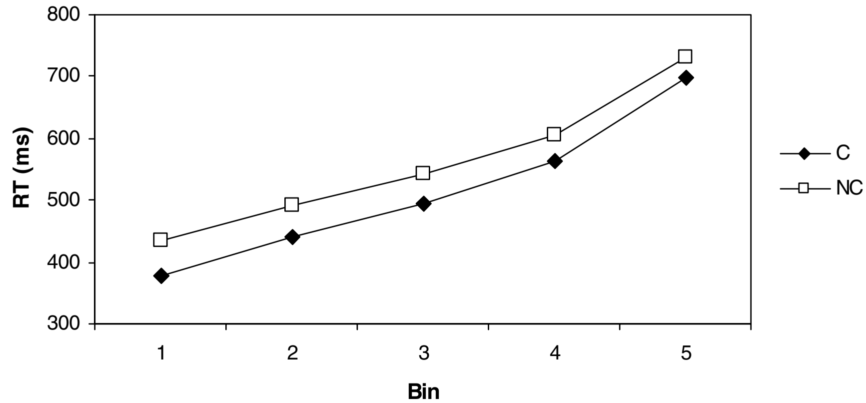

Figure 1. Mean reaction time (RT) in Experiment 1 as a function of Simon correspondence and bin. C = corresponding; NC = noncorresponding.

RT data. Besides the main effect of bin, $F(4, 120) = 395.12$, $p + .001$, $\eta^2_p = .92$, that reflects RTs increasing with bins, the analysis revealed a significant 49 ms Simon effect, $F(1, 30) = 66.53$, $p < .001$, $\eta^2_p = .69$, with faster RTs when stimulus location and response location corresponded (514 ms) compared to when they did not correspond (563 ms). The effect did not differ in the two experimental conditions (44 vs. 55 ms for the permanence and offset conditions, respectively; $F < 1$).

Even though the Simon effect was significant at all bins, it decreased as a function of response time, as indicated by the Simon correspondence × Bin interaction, $F(4, 120) = 9.82$, $p < .001$, $\eta^2_p = .25$ (see Figure 1). An analysis with the magnitude of the Simon effect as dependent variable showed that it was constant in the first three bins and decreased in the last two bins (63, 58, 50, 42, 33 ms, from the first to the fifth bin). The magnitude of the effect did not differ among the first three bins and between the fourth and fifth bins.

We found a significant affordance effect, $F(1, 30) = 9.94$, $p < .01$, $\eta^2_p = .25$, with faster RTs when the side of handle presentation corresponded to the side of the response key (534 ms) compared to when they did not correspond (543 ms).[2] The size of the affordance effect did not differ in the two experimental conditions (6 vs. 12 ms for the permanence and offset conditions, respectively; $F < 1$). There was, however, a significant Affordance correspondence × Condition × Bin interaction, $F(4, 120) = 3.93$, $p < .01$, $\eta^2_p = .12$. In the offset condition, the magnitude of the affordance effect was 3, 5, 9, 14, and 28 ms, from Bin 1 to Bin 5. In the permanence condition it was 8, 7, 7, 9, and 2 ms, from Bin 1 to Bin 5. The effect differed between the two conditions only at Bins 1 and 5. This result may be due to the slightly different RTs evident in the two conditions.

Importantly, the interaction between Simon correspondence and affordance correspondence did not reach statistical significance, $F < 1$, $\eta^2_p = .03$.

The analysis on the arcsin-transformed error proportions showed only a significant Simon effect, $F(1, 30) = 28.31$, $p < .001$, with fewer errors in corresponding (7.9%) than in noncorresponding trials (16.8%).

MT data. Besides the main effect of bin, $F(4, 120) = 302.89$, $p < .001$, $\eta^2_p = .90$, the analysis showed a reverse Simon effect, $F(1, 30) = 17.74$, $p + .001$, $\eta^2_p = .37$, with faster responses when stimulus and pad locations did not correspond (286 ms) compared to when they corresponded (291 ms). The effect interacted with bin, $F(4, 120) = 3.37$, $p < .02$, $\eta^2_p = .10$. Pairwise comparisons showed that the reverse effect was significant at all bins except the first one (−3, −5, −4, −6, −10 ms, from the first to the fifth bin, respectively). The analysis of effect size showed that the only significant difference was that between the first and last bin.

The affordance effect did not reach significance ($F < 1$). There was a significant interaction between affordance correspondence and bin, $F(4,$

[2] An analysis of variance with responding hand and handle position as within-subject factors, and condition as between-subjects factor showed only a significant Responding hand × Handle position interaction, $F(1, 30) = 10.87$, $p < .01$. Right responses were faster when the handle was on the right (532 ms) than when it was on the left (540 ms). Similarly, left responses were faster when the handle was on the left (530 ms) than when it was on the right (541 ms).

120) = 3.76, $p < .01$, $\eta_p^2 = .11$. Even though noncorresponding responses tended to be faster than corresponding responses in the first two bins (-3, -2, 0, 0, 1 ms, from the first to the fifth bin, respectively), this difference never reached statistical significance. No other main effects or interactions reached significance.

The analysis on the arcsin-transformed error proportions revealed no significant main effect or interaction.

Discussion

Experiment 1 showed that response times and accuracy were affected by object location resulting in faster RTs and higher accuracy rates when the object appeared on the same side of the response compared to when it appeared on the opposite side (Simon effect).

Consistent with previous investigations (e.g., Rubichi & Pellicano, 2004), we found a pronounced Simon effect in RTs but, contrary to our expectations, a reverse Simon effect was evident in MTs. To note, the Simon effect typically decreases as response times increase (e.g., Hommel, 1994; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Simon, Acosta, Mewaldt, & Speidel, 1976). However, in the present experiment the Simon effect in RTs was more pronounced than what is normally reported in the literature and was present even for the slowest RTs. Since, as suggested by Ridderinkhof (2002), after some delay the automatically activated response is inhibited, it is possible that this inhibition took place later and manifested itself in MTs instead of RTs.

Response times were affected also by the position of the object's handle, with faster RTs when the handle was on the same side of the response compared to when it was on the opposite side (affordance effect). The observation of an affordance effect in RTs strongly suggests that perceiving a graspable object modulates the selection of a response congruent with the position of its graspable part. By contrast, the absence of an effect in MT suggests that handle position has no effect on movement execution, even when the irrelevant information is visibly present when the movement is executed.

The observation that the two effects were evident in RTs but not in MTs suggests that they both emerge at a stage prior to response execution. The idea that they both emerge at the stage of response selection is apparently inconsistent with the lack of an interaction. However, as suggested by Sternberg (1969) the lack of an interaction does not necessarily indicate that two factors affect different processing stages. It can also indicate that they affect different processes at a common stage. Furthermore, the lack of an interaction is not a conclusive proof of an additive effect between affordance and Simon correspondence. Indeed it may depend on the size of the main effect(s) involved in the interaction. In our study, the affordance effect was rather small in magnitude (9 ms). The relative small size of the affordance effect may depend on the specific response required to the participants. Specifically, in our study participants responded by performing an action directed to a location close to the hand of response (and away from the target object) and unrelated to the actions normally performed to interact with graspable objects. This might have minimised the possibility of observing interactions between interference effects deriving from stimulus location and from the location of the object's handle. Indeed, there are indications that the specific spatial S-R correspondence relations affecting task performance may depend on the way motor responses are executed (e.g., Stins & Michaels, 1997). Furthermore, there is evidence that the characteristics of the required action affect the interference exerted by a handled distractor object, with an affordance-based interference emerging only when participants need to reach for a target object (Pavese & Buxbaum, 2002).

EXPERIMENT 2

In the present experiment we assessed whether the results of Experiment 1 are replicated when the response is more similar to the action normally performed to interact with an object. As in Experiment 1, participants started the trial with their index fingers holding down two buttons and were required to lift one of the two fingers according to the vertical orientation of the stimulus. Differently from Experiment 1, they were then required to reach and touch a rectangular goal area on the screen, located below the location of stimulus appearance. The right finger had to move towards and touch the right area, and the left finger had to move towards and touch the left area. Since the goal area depended on stimulus vertical orientation, when the stimulus and required response did not correspond, the reaching movement was directed to a location other than the stimulus. If the position of the object's handle affects response selection, we should find an affordance effect in response times. If it influences response execution, the effect should be evident in movement times.

Method

Participants. Twelve new students (six females) aged 19–26 years took part in the experiment. They were selected as before.

Stimuli and apparatus. The stimuli were identical to those of Experiment 1. As in the previous experiment, the two lateral buttons of the E-prime response box served for RT acquisition. A touch screen device (KEYTEC Magic Touch) was used for MT acquisition. The response was emitted by touching one of two areas ($14^\circ \times 10^\circ$) located 2 cm below the two locations in which the stimuli could appear. The distance between the two ipsilateral response keys (i.e., the response box key and the touch screen response area) was 37 cm (centre to centre).

Procedure. The procedure was the same as in Experiment 1, except for the following. First, since in Experiment 1 MTs were not affected by the condition manipulation (offset vs. permanence), only the permanence condition was included in Experiment 2. Hence, the stimulus disappeared only after the goal position had been touched or until 1500 ms had elapsed. Second, after releasing one of the two keys in the response box, participants had to touch the ipsilateral touch screen area. MT was thus measured from the release of one of the two lateralised response box keys to the pressing of the corresponding touch screen area. The mapping between the response box key and the touch screen area was always corresponding, i.e., the response box key and the touch screen area were always on the same side.

Results

Data were treated as in the previous experiment. Filtered data were less than 1%.

Two identical repeated measures analyses of variance (ANOVA) were performed on RTs and MTs with Simon correspondence, affordance correspondence, and bin as within-subject factors.

Mean RTs and MTs and percentage errors as a function of Simon and Affordance correspondence are reported in Table 2.

TABLE 2
Mean reaction time (RT) and mean movement time (MT) in Experiment 2 as a function of Simon and affordance correspondence (error percentages in parentheses)

	Affordance			
	Corresponding		*Noncorresponding*	
Simon	*RT*	*MT*	*RT*	*MT*
Corresponding	613 (3.7)	325 (2.5)	608 (4.1)	325 (2.8)
Noncorresponding	631 (9.2)	327 (2.3)	648 (11.3)	326 (3.7)

RT data. Besides the main effect of bin, $F(4, 44) = 109.95$, $p < .001$, $\eta_p^2 = .91$, the analysis revealed a significant Simon effect, $F(1, 11) = 7.10$, $p < .02$, $\eta_p^2 = .39$. RTs were 29 ms faster when stimulus and response were on the same side (610 ms) compared to when they were on different sides (639 ms). The effect decreased with increasing RTs as indicated by the Simon correspondence × Bin interaction, $F(4, 44) = 4.97$, $p < .01$, $\eta_p^2 = .31$. Pairwise comparisons showed that even though the effect was significant at all bins, it was significantly smaller in the last three bins compared to the first two (44, 39, 24, 19, 20 ms, from the first to the fifth bin, respectively).

The affordance effect did not reach significance (622 vs. 628 ms, for corresponding and noncorresponding trials, respectively), $F(1, 11) = 2.48$, $p = .14$, $\eta_p^2 = .18$.[3] Interestingly, there was a significant interaction between Simon correspondence and affordance correspondence, $F(1, 11) = 7.45$, $p < .02$, $\eta_p^2 = .40$. Follow-up analyses showed that the Simon effect was significantly larger for affordance noncorresponding trials (40 ms) compared to affordance corresponding trials (18). Similarly, the affordance effect was significantly larger for Simon noncorresponding trials (17 ms) compared to Simon corresponding trials (-5 ms, *ns*).

[3]The analysis of variance with responding hand and handle position as within-subject factors showed that the interaction between responding hand and handle position did not reach statistical significance, $F(1, 11) = 2.73$, $p = .13$, meaning that the affordance effect was nonsignificant irrespective of responding hand.

The Simon correspondence × Affordance correspondence interaction was further modulated by bin, $F(4, 44) = 5.22$, $p < .01$, $\eta_p^2 = .32$. Separate analyses for the two levels of Simon correspondence showed that the interaction between affordance correspondence and bin was significant only in the Simon noncorresponding condition, $F(4, 44) = 4.84$, $p < .01$, $\eta_p^2 = .91$, with a significant effect in the last bin (8, 8, 7, 22, 41 ms, from the first to the fifth bin, respectively). In the Simon corresponding condition, the affordance effect was absent irrespective of response times, $F(4, 44) = 1.50$, $p = .22$, $\eta_p^2 = .12$ (see Figure 2).

Separate analyses by affordance correspondence showed that the interaction between Simon correspondence and bin was significant only in the affordance corresponding condition, $F(4, 44) = 9.52$, $p < .001$, $\eta_p^2 = .46$, with a significant Simon effect in the first two bins only (40, 34, 20, 6, −11 ms). In the affordance noncorresponding condition, the Simon effect was present irrespective of response times (49, 44, 28, 31, 50 ms), as indicated by the lack of a significant Simon correspondence × Bin interaction, $F(4, 44) = 1.75$, $p = .16$, $\eta_p^2 = .14$.

The analysis on arcsin-transformed error proportions revealed only a Simon effect, $F(1, 11) = 14.85$, $p < .01$, with fewer errors in corresponding than in noncorresponding trials (3.9 vs. 10.2%).

MT data. The analysis showed only a significant main effect of bin, $F(4, 44) = 201.81$, $p < .01$, $\eta_p^2 = .95$, and a marginally significant interaction between affordance correspondence and bin, $F(4, 44) = 2.51$, $p = .055$, $\eta_p^2 = .19$ (−3, −2, −1, 0, 3 ms, from the first to the fifth bin, respectively).

The analysis on arcsin-transformed error proportions revealed no significant main effect or interaction.

Discussion

In Experiment 2 we found a significant Simon effect with faster responses when stimulus and response positions corresponded compared to when they did not. This effect was present in RTs but not in MTs, thus proving that the interference exerted by the irrelevant location of a stimulus affects response selection processes but has no influence on response execution (Rubichi & Pellicano, 2004).

In contrast with Experiment 1, in Experiment 2 the Simon effect interacted with the affordance effect: Stimulus–response correspondence affected both size and time course of the interference exerted by handle–response correspondence and vice versa. In particular, we found that the correspondence between handle position and response position affected performance only when the stimulus did not spatially correspond to the response. Consistently with previous investigations (Phillips & Ward, 2002; Riggio et al., 2008), this effect emerged with slower RTs, suggesting that it does not derive from the processing of the object visual features but requires its semantic processing (Symes et al., 2005; Vainio, Ellis, & Tucker, 2007).

In contrast, when stimulus and response positions corresponded, performance was fast and accurate, irrespective of handle position. Similarly, even though stimulus location exerted a strong influence on response times as indicated by an overall significant Simon effect, the

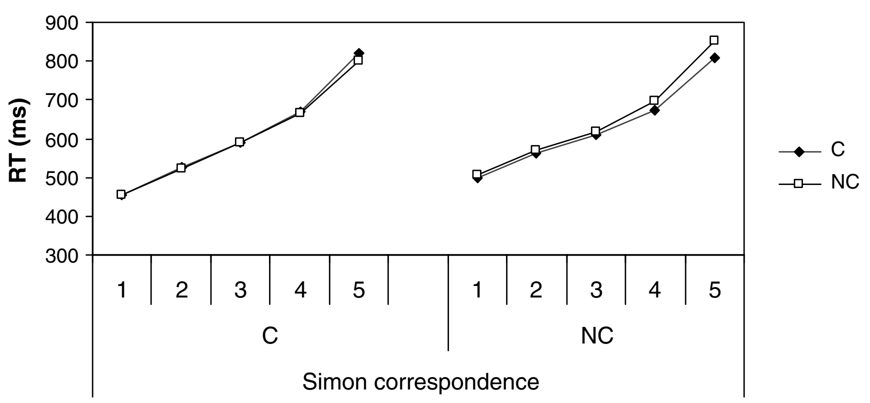

Figure 2. Mean reaction time (RT) in Experiment 2 as a function of affordance correspondence and bin for the two levels of Simon correspondence. C = corresponding; NC = noncorresponding.

magnitude of the Simon effect appeared to be influenced by the correspondence between handle position and response. Indeed, a smaller effect was found when handle and response positions corresponded compared to when they did not. This smaller effect was due to a positive effect with faster RTs decreasing and slightly reversing with slower RTs. When handle and response positions did not correspond a sizeable Simon effect was evident across the RT distribution. Such a time course is comparable with that reported in the study by Rubichi and Pellicano (2004) that used a similar paradigm and stimuli which had no affordance for action (i.e., geometrical shapes).

META-ANALYSIS

To assess whether the interaction between the affordance and Simon effects changes across experiments, we performed a repeated measures ANOVA on the data of the two experiments with affordance correspondence and Simon correspondence as within-subject factors and experiment as between-subjects factor.

The analysis revealed significant main effects of experiment, $F(1, 42) = 7.59$, $p < .01$, $\eta_p^2 = .15$, with faster RTs in Experiment 1 (538 ms) than in Experiment 2 (625 ms), of affordance correspondence, $F(1, 42) = 8.16$, $p < .01$, $\eta_p^2 = .16$, and Simon correspondence, $F(1, 42) = 43.60$, $p < .01$, $\eta_p^2 = .51$. More importantly, there was a significant Affordance correspondence × Simon correspondence × Experiment interaction, $F(1, 42) = 7.25$, $p < .01$, $\eta_p^2 = .15$, confirming that the interaction between affordance and Simon correspondence was significant only for Experiment 2.

To further assess the interaction between the affordance and Simon effects in the two experiments, we subtracted the mean affordance effect evident in Simon corresponding trials from the mean affordance effect evident in Simon noncorresponding trials and computed the 95% confidence interval (Hooper, 2009). In Experiment 1, this difference was 5 ms with a 95% confidence interval of −5.80 to 16.84. In Experiment 2, the difference was −19 ms, with a 95% confidence interval of −39.27 to 0.84. The observation of a narrower confidence interval in Experiment 1 is consistent with the conclusion of a nonsignificant interaction between the two effects. Hence, the lack of an interaction does not seem to depend on the (small) size of the affordance effect.

GENERAL DISCUSSION

The aim of the present study was to investigate the relationship between the affordance effect and the Simon effect and to assess whether they both occur at the same processing stage.

Our results showed that both effects emerged in RTs but not in MTs, thus suggesting that they both arise at a processing stage prior to response execution. Consistently with the results by Symes et al. (2005), Experiment 1 showed no evidence of an interaction between the two effects. In light of this result one may be tempted to conclude that the two effects do not occur at the same processing stage or, if they occur at the same stage, they do not affect the same process, a conclusion in line with the Additive Factor Logic (Sternberg, 1969). However, such a conclusion is brought into question by the finding of a clear interaction in Experiment 2, with a significant affordance effect emerging only in Simon noncorresponding conditions. This is the first report of an interaction between the two effects and, if we strictly apply the Additive Factor Logic, this result is clearly in contrast with the lack of an interaction found in Experiment 1 since it suggests that the two effects are located at the same processing stage.

We believe this inconsistency is only apparent since it may be explained by considering a main limit of the Additive Factor Logic. Specifically, as suggested by Hommel (1993; see also Ridderinkhof, van der Molen, & Bashore, 1995), the Additive Factor Logic may not apply to stimuli like those used in our study, which convey relevant (i.e., stimulus vertical orientation) and irrelevant information (i.e., stimulus location and handle location) in parallel. With such stimuli, the Additive Factor Logic assumptions hold only if the different features of a stimulus are processed with the same speed and transmitted from one stage to the other at the same time in discrete steps. However, as suggested by Miller (1988), it is more plausible to believe that the different features of a stimulus (i.e., stimulus location and handle location) are transmitted to the response selection stage at different points in time (e.g., Pellicano, Lugli, Baroni, & Nicoletti, 2009). As a result, Simon and affordance effects could arise at the same stage but affect response selection asynchronously.

Given these considerations, a possible explanation for the apparently discrepant results would be to assume that the different response requirements of the two experiments changed the temporal dynamics of either the processing of the irrelevant stimulus information and/or of the response selection process. In Experiment 1, similarly to previous studies requiring a button-press response, stimulus position and handle position affect response selection at different points in time, this resulting in an additive relationship. Differently, in Experiment 2 they affect response selection at the same point in time, this resulting in an interaction.[4] Hence, the finding of an interaction seems to depend on the specific type of response required to the participants.

One last point regards the Simon effect. Even though it was modulated by affordance correspondence, with a larger magnitude in affordance noncorresponding conditions, it was always present. The observation that stimulus location exerts a stronger influence compared to handle position is consistent with the results of recent studies suggesting that preparing for a particular type of action increases the saliency of those perceptual dimensions that are relevant for that specific action (Fagioli et al., 2007; Hommel et al., 2001). Since our participants were required to perform a reaching movement, the saliency of stimulus location may have been increased, thus leading to a stronger effect on performance.

In summary, two experiments showed that the appearance of a stimulus brings to the activation of two response codes: one relative to its location in space, responsible for the occurrence of the Simon effect, and the other relative to the location of its graspable part, responsible for the occurrence of the affordance effect. Both effects emerged in RTs but not in MTs and their interaction seemed to depend on the type of action required to perform the task.

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