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Visual salience of 3D and 2D spoons determines S-R mapping and flanker effects

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Abstract

This study tested the hypothesis that affordances for grasping with the corresponding hand are activated more strongly by three-dimensional (3D) real objects than by two-dimensional (2D) pictures of the objects. In Experiment 1, participants made left and right keypress responses to the handle or functional end (tip) of an eating utensil using compatible and incompatible mappings. In one session, stimuli were spoons mounted horizontally on a blackboard with the sides to which the handle and tip pointed varying randomly. In the other, stimuli were pictures of spoons displayed on a black computer screen. Three-dimensional and 2D sessions showed a similar benefit for compatible mapping when the tip was relevant and a small cost of compatible mapping when the handle was relevant. Experiment 2 used a flanker task in which participants responded compatibly to the location of the handle or the tip, and spoons located above and below the target spoon could have congruent or incongruent orientations. The difference between 3D and 2D displays was not obtained in the flanker effect for reaction time. There was little evidence that 3D objects activate grasping affordances that 2D images do not. Instead, we argue that visual salience of the tip is the critical factor determining these correspondence effects.

Keywords

Grasping affordance; spatial compatibility; object-based correspondence effect

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One of the most widely studied phenomena in recent years is the Simon effect and its variants (Hommel, 2011; Proctor, 2011; Simon, 1990). In the typical Simon task, participants make left and right keypress responses to a relevant stimulus property such as colour or shape, whereas the left or right location of the stimulus varies randomly from trial to trial. The standard location-based Simon effect is that responses have a smaller reaction time (RT) when stimulus location corresponds than when it does not (Lu & Proctor, 1995; Simon, 1990). Similar benefits of correspondence are obtained for centred words LEFT and RIGHT and left- and right-pointing arrows, called word-based and arrow-based Simon effects, respectively (Luo & Proctor, 2018). Widespread agreement exists that the Simon effect reflects conflict that occurs when the irrelevant stimulus location information does not concur with the location of the response designated by the relevant stimulus information, which delays responding on those trials (e.g., Luo & Proctor, 2020; Ulrich et al., 2015).

Object-based correspondence effects

Beginning with Tucker and Ellis (1998), researchers have investigated correspondence effects of the handles of graspable objects with keypress responses using variants of the Simon task. Tucker and Ellis presented images of graspable objects centred on a display screen, to which participants made a left or right keypress to indicate whether the object orientation was upright or inverted. Although the location of the entire object did not vary, the handle location varied randomly between the left and right side from trial to trial. A Simon-type correspondence effect

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was obtained for handle side, which Tucker and Ellis attributed to activation of a grasping affordance. According to such an account, this object-based correspondence effect occurs as a consequence of automatic activation of the corresponding hand produced by way of grasping affordance enabled by the object handle.

Tucker and Ellis (1998) understood that this object-based correspondence effect could be a variant of the location-based Simon effect, that is, a consequence of spatial coding of left and right handle locations, which then corresponded or not with the response dictated by the object orientation. To address this possible explanation, they conducted a similar experiment in which the participants responded with the index and middle fingers of a single hand. Their logic was that no correspondence effect should be observed under this condition because the two responses were on the same hand. Unfortunately, the results of this experiment were ambiguous, showing a nonsignificant trend towards a correspondence effect in the analysis of mean RT and a significant effect in the analysis of median RT. Nevertheless, Tucker and Ellis concluded that they had ruled out a spatial coding account of their initial results and could attribute them to a grasping affordance. Subsequent studies provided evidence that the object-based correspondence effect can be obtained with response fingers on the same hand (Cho & Proctor, 2010) and with the left and right feet (Phillips & Ward, 2002). Neither of these response sets should produce this correspondence effect of handle location if it is due to a grasping affordance.

Other researchers have obtained correspondence effects with keypress responses that they also attributed to a grasping affordance, but follow-up studies have consistently shown that such effects are largely due to spatial correspondence of salient visual features with the left–right keypresses. Tipper et al. (2006) obtained results they interpreted as indicating that "affordance" compatibility effects occur when the relevant discrimination involves the action-relevant feature of object shape but not the action-irrelevant feature of colour. They also obtained a larger effect for door handles in a state implying current activation (with the handle angled downwards) than for ones in a passive position (with the handle oriented horizontally). However, Cho and Proctor (2013) and Lien et al. (2014) conducted subsequent experiments with the door-handle stimuli that showed (a) an absence of Simon-type effects when participants made shape or orientation judgements, (b) no smaller Simon-type effects for passive than for active handle states, and (c) different effects for colour judgements as a function of which part of the handle carried the colour. More generally, results indicated that significant correspondence effects for handle location and response location were obtained when the base was centred, and the handle varied in left and right position, but not when the entire object was centred.

More closely related to this study, Pellicano et al. (2010) used torch (flashlight) stimuli that had a graspable handle opposite the light-emitting end. These stimuli yielded what Pellicano et al. called a functional affordance compatibility effect for the handle end when the task required upright versus inverted judgements but not colour judgements. As in Tipper et al.'s (2006) study, the effect was evident when the torch was in an active state (light beam projected at the functional end) but not when it was in a passive state (no light beam). Song et al. (2014) replicated this finding, but noted that the images of the torches contained six strips along the body that were positioned more asymmetrically towards the handle end in the centred images that included the projected beam than in those that did not (the passive-state torches). Song et al. showed that when the handles were removed from the torch stimuli, rendering the barrel markings more asymmetric for both active and passive torches, the correspondence effects were larger. Also, for passive-state torches with no handle, when only half of the markings nearest the end at which light would be projected were included, the correspondence effect reversed to favour that end. The results of the Song et al. study provide evidence for an asymmetric spatial coding account for which the effects are a consequence of correspondence of the left or right position of a salient visual feature with the left or right response, rather than a grasping affordance based on the handle.

Variants of object-based correspondence used as evidence for grasping affordance

Despite the relatively strong evidence that the original object-based correspondence effect and related effects with keypress responses can be attributed primarily to spatial coding, other researchers have continued to try to demonstrate and explain object-based correspondence effects in terms of grasping affordances. One such attempt is that of Pappas (2014), who provided evidence he interpreted as showing that the fidelity of the imaged stimulus objects is a critical factor. He obtained object-based correspondence effects for photographs of objects between-hands but not within-hands, whereas for "schematic" figures the effects were evident for both response sets. Again, though, close examination of the stimuli and arrangement that Pappas used provides an alternative explanation in terms of visuospatial properties of the stimuli rather than affordances (Bub et al., 2018; Proctor et al., 2017).

Proctor et al. (2017) and Masson (2018) and colleagues demonstrated that object photographs produce a correspondence effect for the side to which the handle is located when a pixel-centred procedure is used. Because most of the pixels are in the pan base, the base changes little in location as a function of handle position, whereas the handle switches between distinct left and right locations. However, when an object-centred procedure is used, the pan base is the part that appears in distinct left and right locations across trials, rather than the handle. In this case, experiments from both the labs showed that a reversed correspondence effect is obtained for which the response is faster when it corresponds to the location of the base, that is, to the salient part changing in location across trials.

Masson (2018) summarised his research with Bub on the topic as follows:

> This series of studies highlights the importance of distinguishing between possible accounts of alignment effects. One can quite easily mistake an attentional effect based on spatial correspondence for evocation of a limb-specific action representation (see also Phillips & Ward, 2002). (p. 223)

Recently, Gomez et al. (2018) claimed to have found evidence of a grasping affordance effect using keypress responses for participants who performed a version of the flanker task (Eriksen & Eriksen, 1974). In the standard flanker task, a target stimulus at a centred location (often a letter) is presented on each trial to which the participant is to make a left or right response. The stimulus is flanked by two or more instances of an irrelevant stimulus (often a letter whose identity would be relevant if the letter were in the centre location), which can be congruent or incongruent with the response signalled by the target. The flanker effect refers to the benefit of faster responses and fewer errors when the flankers are congruent than when they are incongruent.

In Gomez et al.'s (2018) study, the stimuli were plastic spoons displayed horizontally to which the participant was to respond with a keypress corresponding to only the handle's left or right location. Two other spoons appeared above and below the target spoon, and their left–right orientation could be congruent or not with that of the target spoon. Gomez et al. compared flanker effects for two-dimensional (2D) images of the spoons shown on a computer display screen and three-dimensional (3D) real-object spoons shown on a display board. Flanker effects were obtained in both cases, but the effect was 8 ms larger with real-object displays (37 ms) than with 2D displays (29 ms), which Gomez et al. attributed to the graspable property of the handle. They reported similar results in a second experiment for which 2D displays were replaced with 3D stereo displays viewed through active shutter glasses. Because the 3D stereo displays added only a binocular depth cue and introduced a difference in the glasses through which the image and object stimuli were viewed, we restricted our experiments to 2D and 3D real-object displays. We consider the results of these two experiments conducted by Gomez et al., along with those of our experiment and two others they reported, in the "General discussion" section.

In a prior study, we followed up on the idea that the spoon's handle produces a grasping affordance using only 2D images, which allows for tighter stimulus control and more trials to be conducted in a given period of time (Xiong et al., 2019). Experiment 1 used simple displays with photographs of a single, centred spoon, for which the side to which the tip was located (as well as the handle) varied randomly from trial to trial. The experiment differed from most others in using a task for which relevant spatial mapping was varied, with some participants told to respond to the location of handle and others to the location of the spoon tip (the functional end, also called the bowl). Specifically, participants were told to respond to left or right handle location by pressing the key compatible with the handle location in one trial block and the incompatible key in the other trial block. A large benefit for the compatible mapping was obtained when the spoon tip was relevant, but a small, nonsignificant cost of the compatible mapping when the handle was defined as relevant. These results suggest a larger influence of the tip than the handle, which is counter to the expectation of the handle automatically activating a grasping affordance but expected on the basis of results obtained with object-centred frying pan images (Lien et al., 2014; Masson, 2018).

Experiments 2 and 3 in Xiong et al. (2019) used photographs of bamboo chopsticks as stimuli, for which the functional and graspable ends differ in being pointed and squared, respectively. Without any further highlighting of images in Experiment 2, East Asian participants showed benefits of a compatible mapping that did not differ significantly between whether the handle or tip was defined as relevant. In Experiment 3, with the chopstick handles coloured red to increase their salience, both East Asian participants and a more diverse sample of participants showed a benefit of the compatible mapping when the handle was task-relevant but not when the functional end was. The results of the three studies thus provided little evidence that pictures of spoons or chopsticks automatically afford grasping of their handles, but instead imply that the left–right location of a visually salient feature (the spoon tip in Experiment 1 and the coloured chopstick handle in Experiment 3) is the primary factor determining these compatibility effects.

Present study

Given this knowledge about 2D displays, in this study we focused on comparing 2D and 3D real-object spoon displays using methods that follow up Xiong et al.'s (2019) Experiment 1 and Gomez et al.'s (2018) Experiment 1 in the present Experiments 1 and 2, respectively. Specifically, participants in Experiment 1 performed the compatible versus incompatible mapping task with 2D displays of the type used in Xiong et al.'s Experiment 1 and 3D real-object displays in which the stimuli were spoons mounted on a blackboard. We anticipated that the outcome would replicate the asymmetric mapping effect pattern found by Xiong et al. for the 2D display. The question of most interest was whether the 3D display would show similar results, indicative of coding on the basis of the salient tip position, or results more indicative of a grasping affordance associated with the spoon handle.

Participants in Experiment 2 performed the flanker task used in Gomez et al.'s Experiment 1, with both 2D and 3D real-object displays mapped compatibly to responses, but in this case with either the spoon tip or handle defined as relevant. Of interest was whether the 3D real-object display would show a larger flanker effect, as reported by Gomez et al., and whether this result pattern would be restricted to judgements when the handle was relevant (as would be expected on the basis of grasping affordance) or also evident when the spoon tip was defined as relevant.

Experiment 1

Experiment 1 was designed to evaluate whether 3D real objects exert a different influence on stimulus–response (S-R) mapping effects compared with 2D images of the objects. We compared the mapping effects of real 3D spoons with those of 2D spoon images. Participants completed choice-reaction tasks in two sessions, one in which 2D spoon images were presented as stimuli and the other in which 3D real spoons were presented as stimuli. Within each session, participants were instructed to respond to the location of one part (either tip or handle) of the spoon with a spatially compatible response in one trial block and a spatially incompatible response in another trial block.

The spoons are similar to the frying pans used in prior studies in that they have a large functional end to which a handle is attached. The spoon stimuli were centred in our prior study and in Experiment 1, meaning that the spoon tip varied more obviously in the left–right location than did the spoon handle. This location-shift relation can be understood by considering the areas of overlap for the tip and handle ends in the two spoon orientations. The area of the tip is about 14.29 cm^2, and there is no overlap when the left and right tip positions are compared. The area of the handle is approximately 7.35 cm^2, but part of the length, 3.15 cm, overlaps in the left and right images, leaving 4.2 cm^2 area of the handle that changes location. Thus, the ratio between the parts (tip vs. handle) that switch between left and right is much larger for the tip than the handle (14.29/4.2 = 3.4).

The larger compatibility effect with tip-relevant than with handle-relevant in our prior study (Xiong et al., 2019) is in agreement with this analysis, and we expected to replicate that result for 2D images. If the salient tip is the primary factor with 3D objects, they also should show the same result pattern to a similar extent. If the grasping affordance hypothesis (Tucker & Ellis, 1998) holds for 3D objects (Gomez et al., 2018), the benefit for

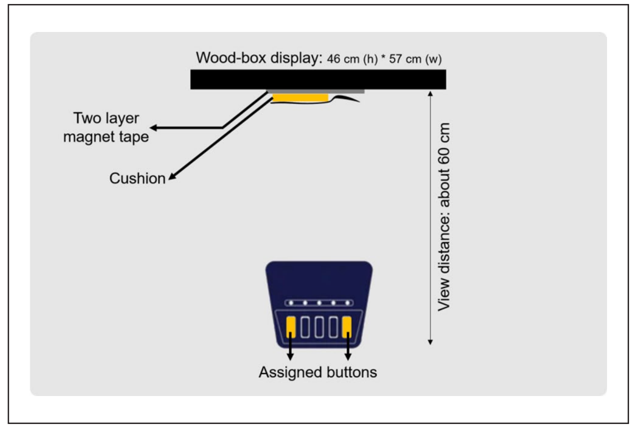

Figure 1. A bird's-eye view of the 3D object display layout and the response keys on Chronos in Experiments 1 and 2.

the spatially compatible mapping over the incompatible mapping should be larger when the handle is relevant than when the tip is relevant.

Method

Participants. Fifty-six students (27 females; $M_{age} = 19$; six left-handed and one ambidextrous[1]), the same number as in Xiong et al.'s (2019) experiments, participated in the study. All participants in this and the remaining experiment (a) were enrolled in an introductory psychology course at Purdue University and received research credits, (b) reported to have normal or corrected-to-normal vision and audition, (c) were naïve to the purpose of the study, and (d) obtained informed consent.

Apparatus and stimuli. Stimulus presentation and response recording were achieved by means of E-Prime 3.0 (Psychology Software Tools) installed on a PC workstation. Participants were seated in front of a 76-cm-high table on which a Chronos response box with a row of five response buttons was placed. A wood-box display (height × width: 46 cm × 57 cm) was placed to the left-hand side of a 19-in. LCD monitor in front of participants. Instructions and 2D image stimuli were presented on the LCD monitor. For the 3D real-object session, the spoon was held in position using cushion and magnet tape, which was fixed to both the convex side of the spoon and the surface of the black wood-box display (see Figure 1). Two-dimensional images were pictures taken from 3D real objects. Both the LCD and wood-box displays were placed 60 cm from participants, as controlled by a chinrest.

Responses were made by pressing the leftmost and rightmost buttons on Chronos with the corresponding index finger. The Chronos was centre-aligned with 2D or 3D real-object displays in the corresponding session. Response feedback and white noise were presented through a SONY headphone set.

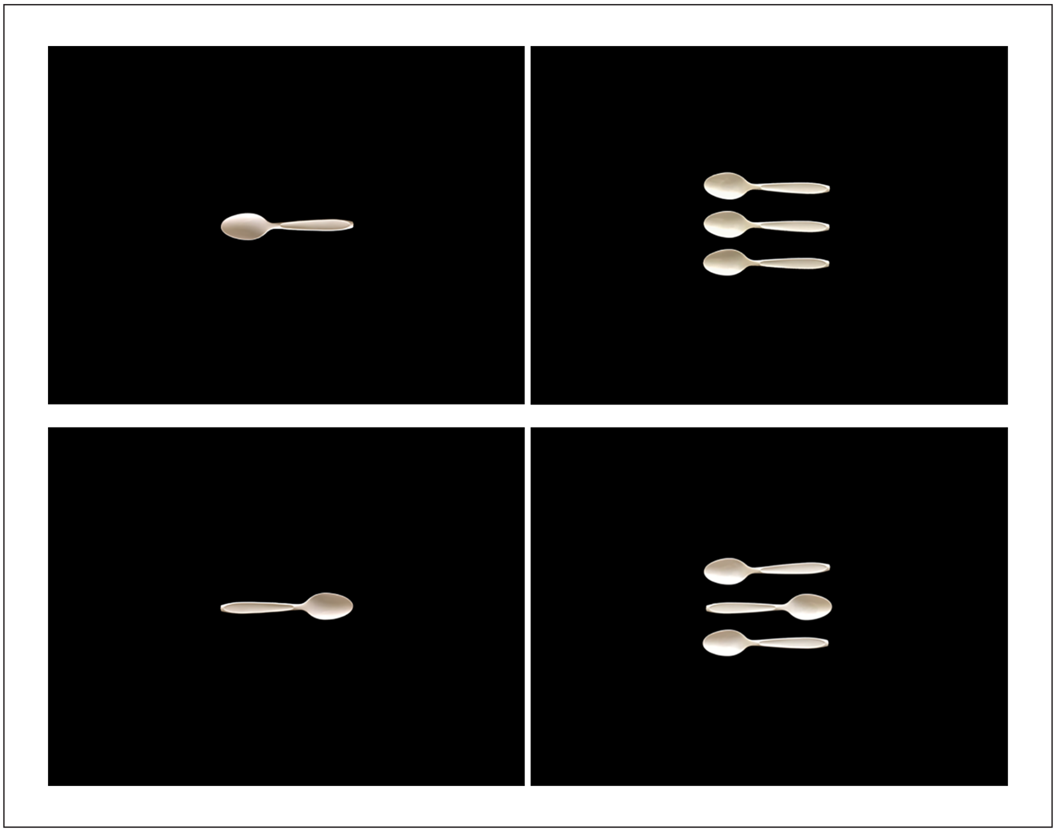

Figure 2. Examples of stimuli presented on a dark board with the (target) tip located to the left (top row) and to the right (bottom row). Left column illustrates the 2D images of the real-object spoons, used in Experiment 1. Right column illustrates the 2D images of congruent trials (top row) and incongruent trials (bottom row) used in Experiment 2.

Visual stimuli were 2D spoon images or 3D real spoons with the spoon tip located to the left or to the right (see Figure 2, left column). The sizes of the real spoon and the spoon image were the same (15.6 cm from tip to handle and 3.7 cm at the widest point). Within each trial, the real spoon or the spoon image was centred at the vertical and horizontal midpoint on a black background and subtended $14.6° \times 3.5°$. The 2D stimuli were created by taking a photograph of the mounted 3D spoon with the handle to the left and the tip to the right and rotating the image 180° to produce the stimulus with the tip to the left and the handle to the right. Consequently, lighting highlights differed across the two spoon orientations, as in Figure 2, left column, for the 2D stimuli but not the 3D stimuli. Evidence discussed in the "Discussion" section of this experiment indicates that any impact of this lighting difference on the mapping effects of interest was minimal. In both 2D and 3D sessions, PLATO liquid crystal occlusion glasses (Translucent Technologies, Toronto, Ontario, Canada), which can be opaque (closed) and transparent (open), were used to control the stimuli's viewing time.

Procedure. The part of the spoon to which the participant was told to respond was varied between participants. Half of the participants were instructed to respond to the tip and the other half to the handle. Each participant performed one session with 2D spoon images and the other session with 3D functional spoons. There was a break between the two sessions, in which participants were asked to have a rest outside of the lab room. Within each session, the responding part was presented to the same side as the correct response for the compatible block, whereas the responding part was the opposite response for the incompatible block. Each participant was instructed to respond to the assigned part with spatially compatible responses in the compatible block and spatially incompatible responses in the incompatible block. The two blocks were separated by a self-paced break. The order of the two sessions was counterbalanced between subjects. The sequence of compatible and incompatible blocks was kept the same between the two sessions for each participant but counterbalanced between participants. Each block included 40 trials, preceded by eight practice trials.

For the 2D session, a spoon image with a left tip or a right tip appeared randomly and equally often, centred on the screen. Within the 3D real-object session, the LCD monitor was turned perpendicular to the participant, and the stimulus configuration was displayed for the experimenter. For each trial, the experimenter placed the real spoon on the wood-box display based on the stimulus

Table 1. Mean correct reaction time (RT) in milliseconds and percentage error (PE), with standard error in parentheses, as a function of relevant part, dimension, and compatibility in Experiment 1 and congruency in Experiment 2.

Experiment	Relevant part	Mean RT		PE	
		Compatible	Incompatible	Compatible (%)	Incompatible (%)
	Tip_2D	429 (24)	472 (26)	0.3 (0.3)	0.2 (0.2)
1	Handle_2D	491 (24)	474 (26)	1.5 (0.3)	0.4 (0.2)
(SRC)	Tip_3D	444 (26)	489 (28)	0.5 (0.2)	0.9 (0.4)
	Handle_3D	471 (24)	469 (28)	0.9 (0.3)	0.8 (0.4)
		Congruent	Incongruent	Congruent	Incongruent
	Tip_2D	484 (22)	528 (23)	0.3 (0.1)	3.3 (0.5)
2	Handle_2D	536 (22)	586 (23)	0.3 (0.1)	1.2 (0.5)
(Flanker Task)	Tip_3D	483 (23)	527 (24)	0.8 (0.2)	2.9 (0.5)
	Handle_3D	541 (23)	594 (24)	0.4 (0.2)	2.3 (0.5)

Note. SRC = stimulus–response compatibility.

configuration on the LCD monitor. The other aspects of the procedure were the same for both sessions. Each trial began with the presentation of a 10-s waiting period, during which the PLATO glasses were opaque. White noise was played during the first 9 s of the initial waiting period on all trials to mask any sounds generated during mounting of the stimuli for the 3D session. Next, the PLATO glasses opened to reveal the stimulus and remained transparent until the participants' response. A 1,000-ms auditory error tone was presented after an incorrect response or if no response was detected within 2,000 ms of stimulus onset.

The experiment was conducted in a well-lit room. Participants were seated comfortably on a chair and were instructed to put their index fingers on top of the response buttons during the experiment. Prior to each trial block, they placed their head in the chinrest. For each mapping, the experimenter went through the instructions and practice with the participant and stayed in the room for the test trials. The whole experiment took approximately 1 hr.

Results

In both experiments, only correct trials were included for RT analysis. Trials with premature responses (RT < 150 ms) or for which RT > 2.5 standard deviation (*SD*) above each participant's overall mean were excluded (0.8% for the tip condition and 1.0% for the handle condition). For analysis of the spatial compatibility effect, mean RT and percentage error (PE) of compatible and incompatible mappings were calculated for each participant. Repeated-measures analyses of variance (ANOVAs) were carried out with two within-subjects factors (Compatibility: compatible, incompatible; Dimension: 2D, 3D) and one between-subjects factor (Spoon Relevant Part: tip, handle).

Mean RT. Table 1 lists mean RT and PE for each condition. Overall, mean RT was 17 ms shorter for compatible mapping than for incompatible mapping, but the main effect of compatibility only approached statistical significance, $F(1, 54) = 3.91$, $p = .053$, $\eta_p^2 = .061$. Neither the main effect of relevant part nor the main effect of dimension was significant, $F\text{s} < 1.0$. Of more importance, the Compatibility × Relevant Part interaction was significant (see Figure 3), $F(1, 54) = 9.20$, $p = .004$, $\eta_p^2 = .146$: The tip-relevant condition showed a 44-ms compatibility effect, $F(1, 27) = 15.17$, $p = .001$, $\eta_p^2 = .360$, whereas the handle-relevant condition showed a −10-ms compatibility effect, $F < 1.0$. The dimension variable showed no significant impact on the compatibility effect or the three-way interaction with compatibility and relevant part, $F\text{s} < 2.03$. The absence of three-way interaction signifies that the compatibility effect pattern differed little, if any, between 2D and 3D real-object displays.

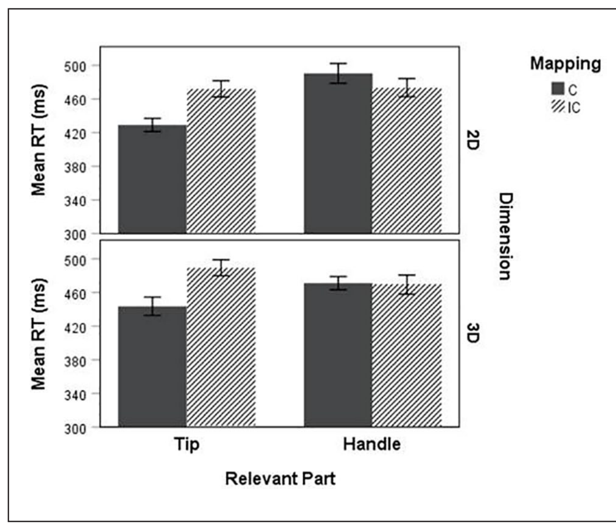

Figure 3. Mean RT as a function of Spoons' Relevant Part (tip, handle), Mapping (C: compatible, IC: incompatible), and Dimension (2D, 3D) for Experiment 1. Error bars represent ± 1 standard error of the mean calculated based on Cousineau's (2005) method for within-subject variables.

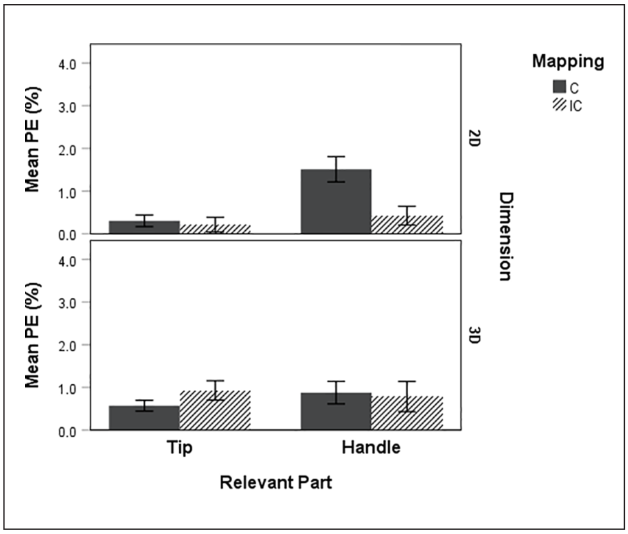

Figure 4. Mean percentage error (PE) as a function of Spoons' Relevant Part (tip, handle), Mapping (C: compatible, IC: incompatible), and Dimension (2D, 3D) for Experiment 1. Error bars represent ± 1 standard error of the mean calculated based on Cousineau's (2005) method for within-subject variables.

Mean PE. The PE of compatible mapping (0.8%) did not differ from that of incompatible mapping (0.6%), $F(1, 54)=1.73$, $p=.194$, $\eta_p^2=.031$, nor did the error rate of the tip condition (0.5%) differ significantly from that of the handle condition (0.9%), $F(1, 54)=2.57$, $p=.115$, $\eta_p^2=.045$. The main effect of dimension was not significant either, $F(1, 54)=1.08$, $p=.304$, $\eta_p^2=.020$. However, the two-way interaction of Compatibility × Relevant Part was significant (see Figure 4), $F(1, 54)=4.44$, $p=.040$, $\eta_p^2=.076$, with −0.6% compatibility effect for the handle session that approximated the .05 criterion level, $F(1, 27)=3.98$, $p=.056$, $\eta_p^2=.069$, and a nonsignificant 0.1% compatibility effect for the tip session, $F<1.0$. The negative compatibility effect in the error data when the handle was relevant is consistent with the RT data, indicating that the spoon tip was still having an effect on performance. Also, the two-way interaction of Relevant Part × Dimension approached the .05 level, $F(1, 54)=3.29$, $p=.075$, $\eta_p^2=.057$. Dimension showed no difference for the handle session, $F<1.0$, but differed for the tip session, $F(1, 27)=4.37$, $p=.046$, $\eta_p^2=.075$. However, the three-way interaction of Compatibility × Relevant Part × Dimension was not significant, $F(1, 54)=2.44$, $p=.124$, $\eta_p^2=.043$. On the whole, these terms reflect that the spoon tip tended to have a larger (opposite) effect on the error pattern than the handle, particularly for the 2D display.

Because our primary interest was in the comparison of 2D and 3D conditions, we conducted separate analyses for the tip and handle. For the tip part, only the main effect of dimension was significant, $F(1, 27)=4.37$, $p=.046$, $\eta_p^2=.139$, showing larger PE for 3D objects than for 2D pictures. For the handle part, only the compatibility effect was at the .05 level, $F(1, 27)=3.98$, $p=.056$, $\eta_p^2=.128$, suggesting larger PE for compatible trials than for incompatible trials when the handle was task-relevant.

Discussion

In Experiment 1, RT was shorter when participants responded to the spatially compatible part of the spoon rather than to the spatially incompatible part, but this benefit held only for the tip-relevant condition. This advantage for the tip-relevant condition is similar to that found by Xiong et al. (2019) in their Experiment 1 and implies that the left or right location of the spoon tip is more salient than that of the handle (Proctor et al., 2017; Xiong et al., 2019). Nevertheless, this result pattern in RT was similar across the image and object displays of the spoon. There was a tendency in the error data for the spoon tip to exert a slightly larger effect for the 2D image than for the 3D object, but this tendency did not show up as a significant three-way interaction and is opposite of that expected on the basis of the handle affording grasping. Thus, in this experiment, real objects did not elicit a grasping response any more than did images of the objects.

As noted in the "Method" section, because the 2D stimuli were created by rotating the photograph for one orientation by 180° to create the other orientation, the upper or lower position of a lighting highlight differed across the two spoon orientations. The compatibility effects obtained with the 2D stimuli in this experiment (tip-relevant: 44 ms; handle-relevant: −10 ms) closely replicated those reported previously in Xiong et al. (2019) using the original centred spoon images of Gomez et al. (2018) (tip-relevant: 45 ms; handle-relevant: −15 ms), for which the highlighting difference was not present. Thus, it seems to have had little, if any, influence on the results of Experiment 1.

Experiment 2

The flanker task is more complex than the spatial compatibility task used in Experiment 1 because three spoons are displayed simultaneously, for which only one is relevant to selecting the correct response. Even though Experiment 1 showed no significant difference between 2D and 3D displays, Gomez et al. found a smaller flanker effect in RT when responding to 2D rather than 3D real-object displays. However, the difference was only 8 ms. Therefore, one purpose of Experiment 2 was to replicate the larger flanker effect for 3D spoon objects than for 2D spoon images. Because Experiment 1 provided evidence that the spoon tip is more salient than the handle, in agreement with our earlier experiment (Xiong et al., 2019), we added a condition to the flanker task in which participants responded to the spoon tip with both 2D and 3D stimuli. If the results of

Experiment 2 replicate the difference found by Gomez et al. and reflect a grasping affordance, a larger flanker effect for 3D than 2D stimuli should be apparent, and this result should be evident only when judgements are based on the graspable spoon handle.

Method

Participants. Another fifty-six students (19 females; M_{age} = 19.4; seven left-handed) from the same subject pool participated in the study, 28 in the tip condition and 28 in the handle condition.

Apparatus, stimuli, and procedure. These were the same as in Experiment 1 except as noted. Two extra spoons were centred along the horizontal midline of the displays and were positioned 3.8 cm above and below the centred spoon of Experiment 1 as flankers (see Figure 2, right column). The 2D stimuli were created from separate photographs of the centre spoon in different orientations, with the upper and lower spoons positioned in the same or opposite orientation. Consequently, the lighting highlights were consistent across the 2D stimulus sets and matched the highlights for the 3D stimuli.

Each session only had one block with 80 trials preceded by eight practice trials. On half of the trials, the flankers were oriented so that they were facing the same direction as the centred spoon (congruent trials), and on the remaining trials, the flankers were oriented in the opposite direction of the centred spoon (incongruent trials). Each participant responded with a compatible mapping to the assigned part, with the target–distractor relation being congruent or incongruent on a given trial.

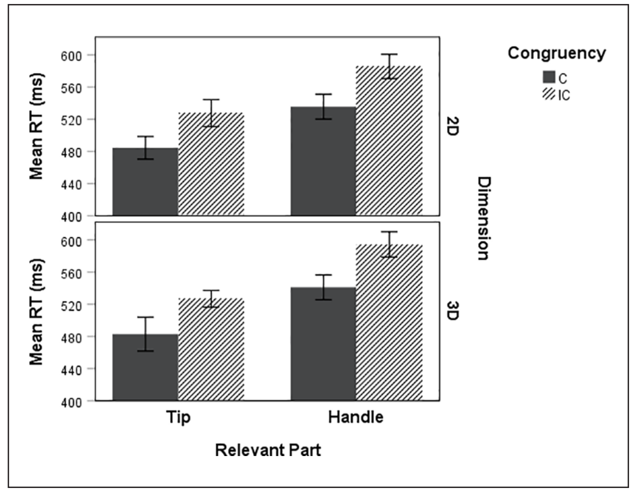

Figure 5. Mean RT as a function of Spoons' Relevant Part (tip, handle), Congruency (C: congruent, IC: incongruent), and Dimension (2D, 3D) for Experiment 2. Error bars represent ± 1 standard error of the mean calculated based on Cousineau's (2005) method for within-subject variables.

Results

Using the same criteria as in Experiment 1, 0.7% of trials for the tip condition and 1.2% for the handle condition were excluded from analysis. Mean correct RT and PE as a function of congruency, relevant part, and dimension were calculated for each participant. ANOVAs of mean RT and mean PE were conducted in a similar fashion as in Experiment 1, but with flanker congruency instead of S-R mapping as a factor.

Mean RT. Table 1 lists mean RT and PE for each condition. Only the main effect of flanker congruency was statistically significant, $F(1, 54) = 174.34$, $p < .001$, $\eta_p^2 = .764$. Responses were 48 ms faster for flanker congruent trials than for incongruent trials, illustrating the flanker effect. The main effect of responding part approached the .05 level, $F(1, 54) = 3.71$, $p = .059$, $\eta_p^2 = .064$: RT was less when the tip was relevant (505 ms) than when the handle was relevant (564 ms). This 59-ms difference is similar to the 45-ms difference without the flanking stimuli in Experiment 1, indicating that the influence of the relative salience of the tip versus the handle on response selection was not affected much by the inclusion of flanker stimuli (see Figure 5). The two-way interaction of Flanker Congruency × Relevant Part was not significant, $F(1, 54) = 1.25$, $p = .268$, $\eta_p^2 = .023$: The flanker effect was of similar magnitude regardless of whether the tip or handle was relevant. Finally, there was no main effect of dimension nor interactions of dimension with the other terms, $F\text{s} < 1.0$, indicating that 2D and 3D displays yielded similar results. The overall flanker effect was 47.0 ms for the 2D display compared with 46.5 ms for the 3D display.

Mean PE. The error rate for congruent trials (0.4%) was less than that for incongruent trials (2.4%), $F(1, 54) = 44.83$, $p < .001$, $\eta_p^2 = .454$. The error rate was also higher for the tip condition (1.8%) than for the handle condition (1.1%), $F(1, 54) = 4.19$, $p = .045$, $\eta_p^2 = .072$. The interaction of Congruency × Relevant Part approached the .05 criterion (see Figure 6), $F(1, 54) = 3.54$, $p = .065$, $\eta_p^2 = .061$. For congruent trials, there was no difference between relevant part, $F < 1.0$. However, for incongruent trials, the error rate was larger for the tip (3.1%) than for the handle (1.8%), $F(1, 54) = 4.31$, $p = .042$, $\eta_p^2 = .074$. There was no main effect of dimension, $F(1, 54) = 2.17$, $p = .146$, $\eta_p^2 = .039$, or its interaction with congruency, $F < 1.0$. Nevertheless, the three-way interaction of Congruency × Relevant Part × Dimension was significant, $F(1, 54) = 4.12$, $p = .047$, $\eta_p^2 = .071$. Specifically, the two-way interaction of Congruency × Relevant Part was evident for the 2D session, $F(1, 54) = 7.57$, $p = .008$, $\eta_p^2 = .123$, but not for the 3D session, $F < 1.0$. For the 2D display, the congruency effect was 3.0% for the tip and 0.9% for the handle, whereas for the 3D display, the congruency effects between the tip and the handle were

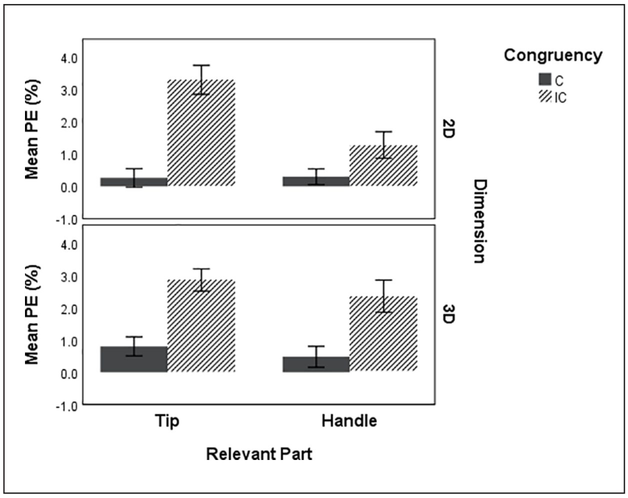

Figure 6. Mean PE as a function of Spoons' Relevant Part (tip, handle), Congruency (C: congruent, IC: incongruent), and Dimension (2D, 3D) for Experiment 2. Error bars represent ± 1 standard error of the mean calculated based on Cousineau's (2005) method for within-subject variables.

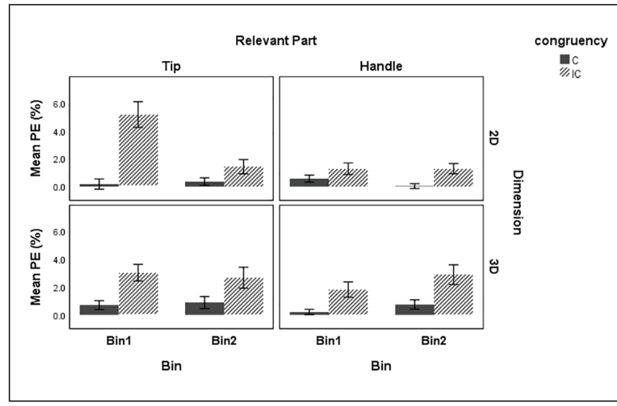

Figure 7. PE bin analysis results for Experiment 2. Mean PE as a function of Bin (Bin1, Bin2), Spoons' Relevant Part (tip, handle), Congruency (C: congruent, IC: incongruent), and Dimension (2D, 3D) for Experiment 2. Error bars represent ± 1 standard error of the mean calculated based on Cousineau's (2005) method for within-subject variables.

similar, 2.1% versus 1.9%. Thus, in the error data, but not the RT data, incongruent flankers for the salient spoon tip created relatively more difficulty with 2D pictures.

Alternatively, the three-way interaction follow-up analysis can be done by examining the results of tip and handle separately, as in Experiment 1. For the tip part, there was a main effect of congruency, $F(1, 27)=26.34$, $p<.001$, $\eta_p^2=.494$. But the main effect of dimension (2D vs. 3D), $F<1.0$, as well as its interaction with congruency was not significant, $F(1, 27)=2.13$, $p=.156$, $\eta_p^2=.073$. For the handle part, the main effect of congruency was also significant, $F(1, 27)=19.20$, $p<.001$, $\eta_p^2=.416$. In addition, there was a main effect of dimension, $F(1, 27)=5.11$, $p=.032$, $\eta_p^2=.159$, indicating larger PE for 3D objects than for 2D pictures. The two-way interaction of Congruency × Dimension was not significant, $F(1, 27)=1.99$, $p=.170$, $\eta_p^2=.069$.

Because an influence of grasping affordance is presumed to be automatic, any difference between 3D and 2D displays due to a grasping affordance should be more evident for the faster responses than for the slower ones. To evaluate this possibility, for each participant, we partitioned the rank-ordered RT for all trials in a condition into two bins, the shortest 50% and the longest 50%. For each bin, we tallied the number of errors and divided by the total number of trials in that bin. An ANOVA similar to the main analysis but including bin as another factor showed similar results as the main analysis. Also, three effects involving bin were significant: the two-way interactions of Bin × Dimension, $F(1, 54)=10.42$, $p=.002$, $\eta_p^2=.162$, Bin × Relevant Part, $F(1, 54)=4.24$, $p=.044$, $\eta_p^2=.073$, and the three-way interaction of Bin × Relevant Part × Congruency, $F(1, 54)=4.74$, $p=.034$, $\eta_p^2=.081$. The bin distributions are shown in Figure 7.

Follow-up analyses of the interactions indicated the following. For the 2D condition, more errors were made in the first bin (1.8%) than in the second bin (0.8%), $F(1, 55)=10.93$, $p=.002$, $\eta_p^2=.166$, whereas for the 3D condition error rates did not differ between the two bins (first bin: 1.4%, second bin: 1.8%), $F<1.0$. The error rate for the tip condition was nonsignificantly larger in the first bin (2.3%) than in the second bin (1.3%), $F(1, 27)=3.34$, $p=.079$, $\eta_p^2=.110$, but in the handle condition, the error rates showed no significant difference between the first bin (0.9%) and the second bin (1.2%), $F<1.0$. Finally, for the tip condition, the flanker effect was larger in the first bin (3.9%) than in the second bin (1.5%), $F(1, 27)=4.54$, $p=.042$, $\eta_p^2=.144$, whereas for the handle condition, the flanker effects of the first bin (1.1%) and second bin (1.7%) showed no significant difference, $F<1.0$. These latter two findings are opposite of what would be expected if the errors with 3D objects or the handle-relevant condition were due mainly to automatic activation of afforded actions.

Discussion

In Experiment 2, responses were 59 ms faster when participants were responding to the tip location than when they were responding to the handle location, similar to the compatible mapping condition of Experiment 1. Whether the displays were 2D pictures or 3D objects had no significant effect on RT overall and the flanker effect in particular, even when the handle was relevant, different from that of Gomez et al.'s (2018) experiment. However, dimension seemed to impact the PE results of the flanker task. For 2D displays, the flanker effect tended to be larger for the tip than for the handle, whereas for 3D objects, such difference was not significant.

General discussion

The majority of results obtained for object-based correspondence effects with keypress responses indicate that spatial coding is the primary source of effects (Masson, 2018; Proctor & Miles, 2014). Pappas (2014) proposed that 2D pictures of real objects with handles yielded evidence of a grasping affordance that contributed to performance, whereas less realistic depictions do not. However, subsequent research showed the results for pictures to be in accordance with a spatial coding explanation based on the part of the object for which the change in left–right location is most salient (Masson, 2018; Proctor et al., 2017). Gomez et al. (2018) went a step further and provided evidence they interpreted as supporting a view that 3D real objects provide evidence of a grasping affordance with keypress responses. The present experiments were designed to test this conclusion of Gomez et al. using spoons as stimuli, as in their study.

Experiment 1 used a choice-reaction task in which a single spoon, oriented left or right, was presented on each trial, and participants were to respond to the side of the spoon tip or handle with a compatible spatial mapping in one trial block and an incompatible mapping in the other. Results for the 2D session replicated those reported by Xiong et al. (2019) in their Experiment 1, with a substantial benefit in RT for the spatially compatible mapping being obtained when the tip was relevant and a slight, nonsignificant cost when the handle was relevant. This result pattern is consistent with the view that it is the spoon tip's change in left and right locations across trials that is most salient and that draws attention to it, rather than the spoon handle. The question of most interest was whether 3D objects would show a similar pattern of results. In the RT analysis, none of the terms involving 2D versus 3D showed significance: The effect sizes and patterns were similar across the two display types. Thus, the RT results from Experiment 1 point in favour of the 3D object display not being special for the compatibility effects and, more specifically, showed the pattern expected on the basis of the tip being salient instead of the handle. Although Gomez et al. did not use a task for which relevant mapping of a single spoon varied, the results of Experiment 1 are counter to what a grasping affordance account would predict.

Experiment 2 was similar to Gomez et al.'s (2018) Experiment 1 in using the flanker task. In this experiment, participants responded to the spoon tip or handle, but always with a compatible mapping of the specified feature to responses. The target spoon was accompanied by flanking spoons that were either oriented the same as the target spoon or the opposite of it. Responses tended to be faster when the tip was defined as relevant rather than the handle, similar to the results for the compatible mapping in Experiment 1. Also, a flanker effect was obtained. Of importance, this effect did not interact in RT with relevant stimulus attribute or whether the display was 2D images or 3D real objects. The flanker effect was the same size for 2D and 3D, with only a slight, nonsignificant indicator of a grasping affordance contribution with the 3D display.

Despite the nonsignificant results obtained for the RT analyses, differences between 2D and 3D displays were apparent in the PE results. In Experiment 1, no PE compatibility effect was obtained for 3D real objects, but there was a reversed compatibility effect for the 2D display. In Experiment 2, the difference in flanker congruity effect between 2D and 3D displays was qualified by responding to relevant part: For the tip, the flanker effect was 3.0% for the 2D display and 2.1% for 3D real objects, whereas for the handle, the flanker effect was 0.9% for the 2D display but 1.9% for 3D real objects. Thus, across both experiments, the obtained results mainly indicate a large influence of the visually salient feature (tip change) regardless of whether the tip or handle was task-relevant in 2D displays.

The present results are generally consistent with those of almost all direct tests of grasping affordance accounts of object-based correspondence effects with keypress responses (e.g., Masson, 2018; Pellicano et al., 2017; Proctor & Miles, 2014). Any such effects are due primarily to spatial coding of the stimuli and responses. For schematic depictions of graspable objects, photographic pictures of objects, and displays of actual objects, spatial coding of the trial-by-trial changes is the predominant factor determining mapping and Simon-type effects for objects with graspable parts protruding to the left or right. A recent study by Kostov and Janyan (2020) emphasises this point. Across four experiments, when the graspable part varied in left and right location (pixel-centred) such that there were an equal number of pixels located to each side of the photographs, they found handle-based correspondence effects for upright/upside-down and colour judgements. In contrast, when photographs or silhouettes of graspable objects were centred (width-centred) such that there were more pixels in the object base varied in left and right location (as in this study), the correspondence effect was obtained for the base. The one exception to this latter finding was their Experiment 4, in which the stimuli were silhouette outlines, in which case no correspondence effect was evident for the width-centred stimuli. Kostov and Janyan concluded that their results support a visual salience account, with effects like those found in this study being a consequence of a low-level perceptual factor of the left–right pixel change from trial to trial for the base attracting attention.

A question is why our Experiment 2 showed no significant difference in the flanker effect across display conditions, whereas Gomez et al.'s (2018) Experiments 1 and 2 did. The answer may lie in overall RT differences evident in their experiments but not ours. For Gomez et al.'s study, the flanker effect was 8 ms larger for 3D objects than for 2D images in Experiment 1 and 16 ms larger for 3D objects than for 3D stereo images in Experiment 2. But, overall RT was also significantly longer for 3D objects than for image conditions, by 25 and 20 ms, respectively. In Gomez et al.'s Experiments 3 and 4, the flanker effects were a nonsignificant 4 ms larger and 1 ms smaller for 3D objects than for 2D images when the stimuli were displayed farther away or behind a transparent barrier, respectively, and the overall RT likewise showed only nonsignificant 7 and 2 ms differences. The intent of these latter experiments was to abolish the hypothesised grasping affordance for 3D objects, but the manipulations mainly acted to increase RT and the flanker effect size for the 2D image condition to a similar level as for the 3D object condition.

Studies that have analysed the flanker effect across the RT distribution, in what are called delta plots, imply that differences in flanker effect sizes can be obtained if overall RT differs between conditions. Burle et al. (2014) and Hübner and Többel (2019) plotted flanker effects for five 20-percentile RT bins. In both studies, when the flanker stimuli onset simultaneously with the target (Burle et al., 2014) or 17 ms in advance (Hübner & Többel, 2019), the flanker effect increased across the five RT bins. An inference of this finding is that as responding is slowed, the overall Simon effect will increase. Consistent with this inference, Burle et al. (2014) found that the flanker effect for RT was significantly smaller for sessions in which participants emphasised response speed compared with sessions in which they emphasised response accuracy (flanker effects of 24 and 33 ms, respectively). In our Experiment 2, in which the viewing conditions were similar to Gomez et al.'s Experiment 1 (i.e., un-occluded views from 60 cm), the equivalent handle-relevant condition yielded an overall RT difference between 3D and 2D of 6.5 ms, and the flanker effects differed by only a nonsignificant 3 ms. Thus, our results evidence that when RT is comparable for the 2D image and 3D object conditions, even if grasping the 3D object could potentially be afforded, the flanker effects are similar for the two conditions.

As we were completing this study, another study claiming evidence for a grasping affordance with keypress responses came out. Azaad and Laham (2019) reported results with keypresses obtained with a method intended to sidestep spatial confounds. They had participants perform a Simon-type task for which the relevant stimulus was one of three colours, and the task was to press, in response to the appropriate colour, a left key with the left index finger, a right key with the right index finger, or both keys. Their stimuli consisted of objects that had one or two handles, with the logic being that the objects afforded grasping with one or two hands, respectively. The results showed a 12-ms Simon-type correspondence effect between the number of handles and the number of fingers/keys. Azaad and Laham interpreted this effect as "suggesting that affordance effects exist independent of spatial compatibility" (p. 1). Although left–right spatial coding effects should be minimised with their method, the method does not rule out other spatial factors, such as size-related effects that have been implicated for studies on precision versus power grips (Proctor & Miles, 2014). We think it likely that spatial coding is still the primary factor in this one-hand versus two-hand Simon-type effect.

Neuroimaging results (e.g., Chao & Martin, 2000; Gerlach et al., 2002) are often cited as evidence for tools and other graspable objects activating their afforded motor responses. For behavioural data for tasks with keypress responses, the main issue of concern is whether the neuroimaging studies provide strong evidence for activation of grasping responses regardless of the action. Ishibashi et al. (2016) performed a meta-analysis of 70 neuroimaging studies on three tool-relevant cognitive tasks: (a) recognition: in which participants observed photos or pictures of objects or performed a nonverbal task that required recognising visual stimuli (e.g., judging them as same or different); (b) naming: in which participants named the objects silently or explicitly; (c) action-retrieval: in which participants retrieved actions associated with common tools, through imagining, planning, or executing the actions. Of relevance for the affordance issue, Ishibashi et al. found that recognition and naming tasks activated similar neural regions but showed substantial differences with the action-retrieval tasks. The action-retrieval tasks produced heightened activation in the left superior parietal lobule and dorsal frontal gyrus, both of which are areas within the dorso-dorsal pathway. This pathway is also called the "grasp" pathway (Binkofski & Buxbaum, 2013), and the fact that activation in it occurred when actions were required but not when the objects were passively viewed or named seems to argue against the idea that a grasping action is activated automatically outside of contexts that require thinking about or generating grasps.

The results of current Experiments 1 and 2 could seem to be in conflict: Different compatibility effects between tip and handle were obtained in Experiment 1, but similar flanker congruency effects between the two relevant parts were evident in Experiment 2. However, the tasks in those experiments target distinct aspects of information processing. For that reason, Kornblum's (1992) taxonomy classifies the tasks into different categories: (a) *S-R compatibility*, for which slower responding with incompatible mapping than compatible mapping is due to the assigned response being in the noncorresponding location; (b) *stimulus–stimulus* (*S-S*) *congruity*, for which slowing of responses arises from the flanker stimuli (and the responses they would activate) conflicting with the centred, target stimulus. That is, the compatibility effects in Experiment 1 reflect differences in task intentions, whereas the flanker interference in Experiment 2 reflects conflict induced by the multiple stimuli.

To summarise, when a person has the task set to make spatially defined keypresses to stimuli, those are the actions that they are primed to make (Xiong & Proctor, 2018). For left and right keypresses, those responses are defined primarily by the left or right response locations, and correspondence effects occur primarily as a function of the match of salient location information with the distinction between response locations. Grasping actions are not part of the task set and, accordingly, seem to contribute little, if any, to response times.

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Note

1. Because spatial compatibility effects are collapsed across left and right responses, differences in reaction time (RT) between dominant and nondominant hands are averaged out. Moreover, the result patterns in both experiments were similar when only right-handed persons were analysed.

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