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ORIGINAL ARTICLE

Object-based correspondence effects for action-relevant and surface-property judgments with keypress responses: evidence for a basis in spatial coding

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Abstract It has been proposed that grasping affordances produce a Simon-type correspondence effect for left–right keypress responses and the location of the graspable part of an object for judgments based on action-relevant properties such as shape, but not on surface properties. We tested the implications of this grasping affordance account and contrasted them with the ones derived from a spatial coding account that distinguishes holistic processing of integral dimensions and analytic processing of separable dimensions. In Experiments 1–3, judgments about the color of a door handle showed a Simon effect relative to the handle's base, whereas judgments about the handle's shape showed no Simon effect. In Experiment 4, when the middle of the handle was colored, the Simon effect was obtained relative to the base, but when the color was at the tip of the handle or near the base, Simon effects were obtained relative to the color location. For Experiment 5, only the base was colored, and the Simon effect was larger for a passive rather than active handle state, as in the color-judgment conditions of Experiments 2–4 in which the colored region overlapped with the base. In Experiment 6, orientation judgments showed no Simon effect, as the shape judgments did in Experiments 1 and 2. The findings of (a) an absence of Simon effects for shape and orientation judgments, (b) no larger Simon effects for active than passive handle states, and (c) isolation of the changing component for color judgments are consistent with the spatial coding account, according to which the distinction between object shape/orientation and color is one of integral versus separable dimensions.

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Introduction

The information-processing approach to human performance assumes that perception and action are mediated by representations, or codes. Therefore, specific behavioral effects are attributed to the codes and processes that underlie performance (Sanders, 1998). Recently, from within the information-processing perspective, several researchers have adopted the concept of affordance, which originated in the ecological psychology approach that espouses the view that perception is direct and not mediated by representations (Gibson, 1979). Representational affordance accounts have been developed to explain compatibility effects obtained with mappings of objects with graspable properties to keypress or handgrip responses (e.g., Tipper, Paul, & Hayes, 2006; Tucker & Ellis, 1998). We refer to such effects with the term *object-based* rather than *affordance*, which is often used (e.g., Galpin, Tipper, Dick, & Poliakoff, 2011; Riggio et al., 2008), because of the former term's neutral connotation. The present study examined the influence of judgment type on object-based compatibility effects for keypress responses that has been attributed to a grasping affordance, and contrasted this account with a hypothesis based instead on a difference between holistic and analytic processing.

Stimulus–response compatibility and Simon effects

Representational affordance accounts of object-based compatibility effects are based empirically on stimulus–response compatibility (SRC) and Simon effects. In spatial SRC tasks, participants make responses (e.g., left or right keypress) based on a stimulus location (e.g., left or right). The SRC effect is such that responses are faster and more accurate when the stimulus and response locations correspond than when they do not (e.g., Fitts & Deininger, 1954). Spatial SRC effects are a function of the relative positions of the stimuli and responses (Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1982). For example, when the hands are crossed such that the left hand presses the right key and the right hand the left key, spatially corresponding mappings of stimulus and response locations still yield faster responses than do non-corresponding mappings (Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977). Thus, SRC effects are typically attributed to response selection being faster when the stimulus and response spatial codes correspond than when they do not (e.g., Proctor & Reeve, 1990; Umiltà & Nicoletti, 1990), and not to the anatomical connections or absolute locations of the stimuli or responses.

Spatial SRC effects occur even when the task involves judgments about a relevant nonspatial stimulus feature such as color. The Simon effect refers to the fact that response time (RT) is shorter when the irrelevant stimulus location corresponds with the response location than when it does not (Simon, 1990; for reviews, see Hommel, 2011, and Lu and Proctor, 1995). The Simon effect is typically attributed to automatic activation of the response code corresponding to the stimulus code. In Kornblum, Hasbroucq, and Osman's (1990) dimensional overlap model, this activation is a consequence of overlap of the irrelevant spatial stimulus dimension with the relevant spatial response dimension. The resulting activation produces faster responding when the activated response code corresponds with the spatial location of the response than when it does not, regardless of the nonspatial stimulus dimension that is being judged (e.g., color, shape).

Choice reactions are often faster when the location of the graspable part of an object, though irrelevant to the task, corresponds with the location of the response than when it does not (Cho & Proctor, 2010, 2011), or, in other words, an object-based Simon effect. Object-based Simon tasks involve various judgments, such as distinguishing upright and inverted objects (Cho & Proctor, 2010, 2011; Tucker & Ellis, 1998), high and low pitch tones (Ellis & Tucker, 2000), and manufactured versus organic objects (Tucker & Ellis, 2001). Typically, which stimulus dimension is relevant does not affect automatic behavior, such as activation of the corresponding response in spatial Simon tasks. Cho and Proctor (2010, 2011) reported similar findings for object-based Simon effects obtained with keypress responses to depictions of frying pan and teapot stimuli for which the pan or body of teapot was centered, with the handle (and spout for the teapot) varying in the left and right positions. For the frying pans, an object-based Simon effect was obtained for both color and upright-inverted orientation judgments; for the teapots, both the spout and handle contributed to the correspondence effects, again, for both color and orientation judgments. Several findings, including that the effects were at least as large when the responding fingers were on the same hand as when they were on different hands, were more consistent with a spatial coding account than a grasping affordance account.

Action-relevant and surface-property judgments

In contrast to the results obtained by Cho and Proctor (2010) when the handles of the stimuli varied in distinct left and right positions, other studies, in which there was little change in position of the handles across trials, have reported evidence that action-relevant judgments of object properties such as orientation and shape affect performance differently than judgments of surface properties such as color and contrast. Tipper et al. (2006) compared object-based Simon effects for color and shape judgments with door-handle stimuli (oriented to the left or right, in a passive or active state) and keypress responses. Half of the participants judged the color (blue/green) of each handle, and the other half judged the shape (round/square; see Fig. 2). The color judgments showed no Simon effect based on handle direction, whereas the shape judgments showed a 25-ms effect, suggesting that the action-relevant judgments automatically activated the action through a grasping affordance. Also, the Simon effect was 36 ms with the handle in an active state (diagonal handle, corresponding to being pressed down to open the door) compared to 14 ms in a passive state (horizontal handle, corresponding to the resting position), which the authors interpreted as indicating that the action affordance was stronger when the door handle was depressed.

Pellicano, Iani, Borghi, Rubichi, and Nicoletti (2010) used a horizontally oriented torch (lantern-type flashlight) as stimulus (illustrated in Fig. 5, discussed later), again with keypress responses. The flashlight had a graspable handle on one end and a goal-directed portion (light emitting) on the opposite end. One group of participants judged the upright/inverted orientation of the flashlights, whereas another group judged their blue/red color. For upright/inverted orientation judgments, an overall 5-ms Simon effect relative to the left or right handle position was obtained. Consistent with Tipper et al. (2006), the effect was evident for trial blocks in which the flashlight was depicted in an active state (i.e., with a light beam), but not for those in which it was depicted in a passive state (i.e., with no light beam). For color judgments, there was a Simon effect of 10 ms, but in the opposite direction, that is, relative to the light-emitting end, which did not depend on whether the state was active or passive.

Another method is to examine the effect of a prime stimulus on performance. In Loach, Frischen, Bruce, and Tsotsos's (2008) Experiment 1, participants made texture judgments (diamond plate metal or wood grain) with keypress responses to the second of two successively presented door handles. The graspable parts of the prime and probe handles were always to the same side, but the prime handle could be rotated 0°, 20°, 40°, or 60° relative to the probe handle, which was always horizontal. An 8-ms Simon effect for door-handle side and response location was evident when the orientations of the prime and probe handles were identical, but this reversed to a 12-ms benefit for noncorrespondence when the orientations differed by 20° or 40°.

In contrast, when the blue or green color of the door handles was judged in Loach et al.'s (2008) Experiment 2, there was no significant Simon effect at any orientation. Bub and Masson (2010 Experiment 2) had participants judge the blue or green color of a beer mug or teapot with the handle oriented to the left or right by making a left or right keypress. The object appeared in grayscale as a prime 195 or 630 ms before it changed color. Similar to Loach et al., no Simon effect was evident for either delay.

The above researchers all concluded that activation of the response corresponding to the handle did not occur when the task was color discrimination. Rather, the results have been taken to imply that a grasping affordance is activated that affects keypress responses only when the discrimination involves an object property related to grasping (e.g., orientation or shape). However, Bub and Masson (2010) have questioned this position, arguing, "Very few studies have convincingly shown evidence that lateralized hand action representations are automatically evoked by a handled object and influence a left- versus right-handed key-press response" (p. 342). Because Tipper et al.'s (2006) study provides the strongest evidence of this type, we focused on the Simon effects obtained with door-handle stimuli under various judgment conditions in the current study.

Present experiments

In the present experiments, we used Tipper et al.'s (2006) door-handle stimuli, presented with the handle centered to

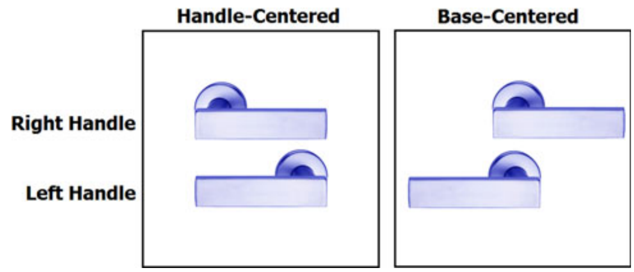

Fig. 1 Examples of handle-centered and base-centered handle stimuli

remove the salient laterality component that is present when the handle varies between the left and right sides [see Fig. 1 and the comparison with Cho and Proctor's (2010, 2011) studies in "General discussion"]. Also, we adopted Tipper et al.'s and Pellicano et al.'s (2010) criteria for evidence of a grasping affordance: (1) a Simon effect relative to the handle for shape and orientation judgments; (2) a larger Simon effect relative to the handle for the active than passive state for shape judgments and orientation judgments.

In the Introduction to their study, Tipper et al. (2006, p. 494) stated,

> It should be noted that in initial pilot studies, action affordance effects with the door-handle stimuli were very small. Therefore, in an attempt to increase the affordance effects, and also to specifically increase the sense of active object state, we presented short video clips of a hand reaching toward, grasping, and pushing the handle down, prior to starting the experiment.

Consequently, Bub and Masson (2010) concluded that judgments of object properties in themselves were not sufficient to yield the object-based Simon effects for keypresses, but that the prior video clips provided an action context that caused coding of handle alignment. In Experiment 1, we directly tested this possibility by having participants perform shape judgments with the door-handle stimuli after viewing a prior video clip showing their operation or without viewing such a clip.

Having found no Simon effect either with or without the prior video, Experiment 2 was designed to determine whether the color and shape judgments in fact yield different patterns of Simon effects with the door-handle stimuli. This allowed us to confirm the results obtained for shape judgments in Experiment 1, as well as to verify whether a tendency toward a reversed Simon effect for color judgments, evident nonsignificantly for door handles in Cho and Proctor's (2011) Experiment 4 and significantly for the flashlight stimuli in Pellicano et al.'s Experiment 1, was reliable. The remaining experiments examined the implications of an integral-separable dimensions hypothesis to explain the results of

Experiments 1 and 2, which is introduced after those two experiments.

In addition to examining object-based Simon effects for mean RT and percentage of error (PE), analyses of changes in the Simon effect across the RT distributions are needed for detailed and dynamic evaluations. De Jong, Liang, and Lauber (1994) performed RT distribution analyses, dividing the distributions into bins and reporting the Simon effect for each bin. De Jong et al. found that the Simon effect for visual tasks was largest at the short RT bins and decreased as RT increased. Likewise, in Cho and Proctor's (2010) study, the Simon effect in the standard Simon-task condition (a colored circle located to the left or right) decreased across the RT distribution. This decreasing pattern has been attributed to rapid activation of the corresponding response, followed by a decrease in activation (for review, see Proctor, Miles, & Baroni, 2011). In contrast, with frying pan (Cho and Proctor 2010) and teapot stimuli (Cho & Proctor, 2011), for which the handle was located to the left or right, the object-based Simon effect increased across the RT distribution, suggesting that activation of the response corresponding to the handle took longer to occur (see Derbyshire, Ellis, & Tucker, 2006; Phillips & Ward, 2002; Tucker & Ellis, 2001, for other examples of increasing object-based Simon effect functions).

Experiment 1

Prior to their experiment, Tipper et al. (2006) showed their participants a video clip displaying four 2-s sequences of a hand (male/female and left/right hands) reaching for and operating a door handle, whereas we did not. Bub and Masson (2010) noted that Simon effects attributable to grasping affordances are not typically observed with keypress responses and concluded that the prior video clip likely was an important part of Tipper et al.'s procedure. Specifically, they speculated, "Key-press responses are not sufficient to evoke alignment effects without prior contextual prompts that encourage observers to consider the function of handled objects" (p. 347). The prompt in Tipper et al.'s study to which they referred was the video clip. Consequently, in Experiment 1 we had participants perform the shape-judgment task, which had shown large object-based Simon effects in Tipper et al.'s study, manipulating whether or not they were shown a video clip at the beginning of the session.

Method

Participants

Forty students who had enrolled in introductory psychology classes participated for experimental credits. Twenty participants were randomly assigned to the video clip condition, and 20 to the no-video clip condition. All had normal or corrected-normal vision and normal hearing.

Apparatus and materials

Stimuli for the shape-judgment task were pictures and tones generated by Micro Experimental Laboratory (MEL 2.01), which controlled the experiment. For all conditions, the participant sat directly in front of the monitor, at a distance of approximately 60 cm. Responses were registered by presses of one or the other of two adjacent keys on the bottom row of the computer keyboard (the *B* or *N* key) with the left or right index finger. The stimuli used were those of Tipper et al. (2006), with the handle location being to the left or right (see Fig. 2) of the base, and the instructions were worded identically to theirs. The stimuli were of the same size as in their study, being generated from their files on a 19-in. monitor (1,280 × 1,024 resolution). The lengths of the square and round door handles were 9.5 and 10 cm, respectively, with the base attachment being 3.5-cm diameter. The handle was centered on the screen, with the base varying in position (see Fig. 1, handle centered). The video, seen by half of the participants, consisted of four 2-s clips of male and female hands reaching for and operating a door handle with the left and right hands, as in Tipper et al.'s (2006) study.

Design and procedure

Each participant received two blocks of 176 trials in which each object occurred equally often in each color (blue or green) and with a left or right handle location, with order randomized for each participant. All participants were instructed to make a left or right response depending on whether the door handle was round or square (see Fig. 2). Participants in the video condition were shown the video of people operating the door handle prior to receiving the specific instructions for the experiment, whereas participants in the no-video condition were not shown the video. Participants had the same stimulus–response mapping for the relevant shape dimension across the trial blocks and were required to take a 1-min break between blocks, as in Tipper et al.'s study. Instructions were to respond as fast and accurately as possible, without making many errors. Each participant received 16 practice trials before the first block.

Each trial began with onset of the blank screen for 1,000 ms, then the stimulus appeared and remained present until a response was made or for 1,500 ms, at which time the trial was terminated if no response had been made. Participants were not given feedback on response latencies, but errors were immediately followed by a short tone

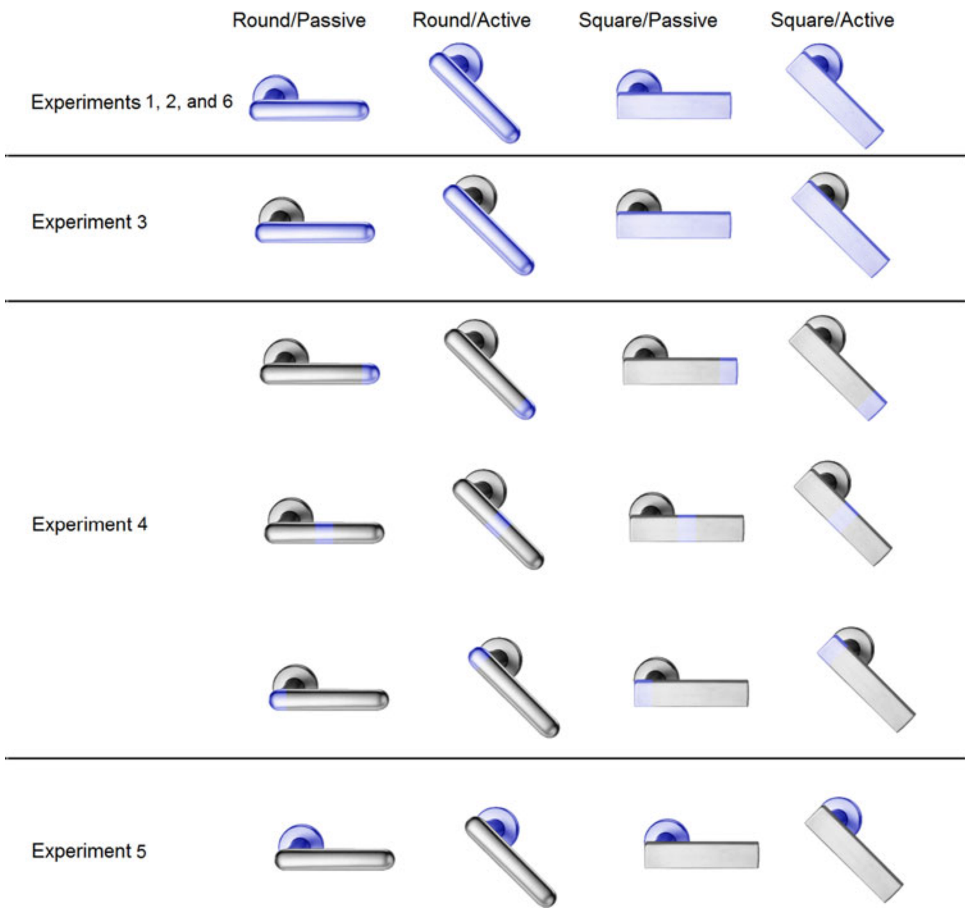

Fig. 2 The right-facing door-handle stimuli used in Experiments 1 and 6 (*blue only*). The left-facing stimuli were similar but with the handle to the left side. For Experiments 1, 2, and 6, the entire door handle was colored; for Experiment 3, the handle itself but not the base was colored; for Experiment 4, a section of the handle at the tip, middle, or base end was colored; for Experiment 5, only the base was colored. Adapted from Tipper et al. (2006). Adapted with permission (color figure online)

(500 ms) from the computer, followed by onset of the next trial.

Results

Mean RT and PE

The mean RT and PE data are shown in Table 1. The data were analyzed as a function of condition (video, no-video) as a between-subjects variable and trial block (first half, second half), action state (active, passive), and correspondence (whether handle side corresponded or not with the location of the correct response) as within-subject variables. We defined correspondence with respect to relative location of the handle, as is typical in studies of the object-based Simon effect. Consequently, a negative Simon effect indicates a benefit for correspondence with the base location rather than the handle.

There was no main effect on either RT or PE of the video manipulation, $F(1,\ 38) = 2.71$, $MS_e = 15{,}609$, $p = .11$, and $F < 1.0$, respectively, or correspondence (mean Simon effects of 1 ms and -0.1 %), Fs < 1.0, and no two-way interaction of correspondence with the video manipulation for RT, $F < 1.0$. Contrary to the hypothesis that viewing the video of hands operating the door handle would induce an object-based Simon effect, the difference in RT for noncorresponding and corresponding trials was approximately 1 ms both with and without the video. The interaction of correspondence with the video manipulation almost attained the .05 level for PE, $F(1,\ 38) = 3.93$, $p = .055$, $\eta_p^2 = .09$, but the Simon effect tended to be slightly negative (–0.5 %), favoring noncorrespondence with the handle, when the video clip was viewed and slightly positive (0.4 %) when it was not viewed, counter to the video-induced affordance hypothesis.

For RT, the only interaction including the video factor that neared significance was the three-way interaction with handle state and correspondence, $F(1,\ 38) = 2.89$, $p = .097$ [for PE, $F(1, 38) = 1.0$]. Without the video clip, the Simon effect was 1 ms for both active and passive handle states, whereas with the video clip, the Simon effect was slightly negative for the active state (-5 ms) but slightly positive for the passive state (8 ms), a difference that was significant, $F(1,19) = 4.53$ $MS_e = 171$, $p < .05$, $\eta_p^2 = .19$. All other terms were not significant, Fs < 3.21, ps $> .08$.

Table 1 Mean response times (RT) and percentage errors (PE) as a function of correspondence and action state, and the Simon effect in Experiments 1 and 2

Experiment	Judgment condition	Action state	Corresponding		Noncorresponding		Simon effect	
			RT (SD)	PE (SD)	RT (SD)	PE (SD)	RT	PE
1	Shape judgment without video clip	Active	413 (60.91)	2.1 (1.75)	415 (63.18)	3.0 (2.51)	2	0.9
		Passive	415 (64.86)	2.1 (2.08)	416 (64.04)	2.1 (2.05)	1	0.0
	Shape judgment with video clip	Active	449 (67.54)	2.6 (2.60)	444 (61.68)	2.0 (1.96)	−5	−0.6
		Passive	444 (61.73)	2.3 (2.36)	452 (63.15)	1.8 (1.97)	8	−0.5
2	Color judgment	Active	386 (56.93)	1.8 (2.10)	384 (55.95)	1.5 (1.55)	−2	−0.3
		Passive	393 (60.02)	1.9 (1.70)	380 (57.78)	1.1 (1.54)	−13*	−0.8*
	Shape judgment	Active	419 (55.12)	1.9 (1.73)	418 (58.29)	2.3 (2.24)	−1	0.4
		Passive	421 (57.54)	1.7 (1.69)	423 (59.16)	1.9 (1.75)	2	0.2

* $p < .05$

RT distribution analyses

For all conditions, RTs for noncorresponding and corresponding trials were rank ordered for each participant and equally divided into four bins in which Simon effects were calculated. ANOVA of the Simon effect with the four bins and two conditions as factors showed neither a main effect of bin nor interaction of bin with condition, Fs < 1.5. The Simon effect did not vary across the RT bins for either condition (see Fig. 3).

Discussion

For participants who viewed the door-handle video prior to the experimental session, as in Tipper et al.'s (2006) experiment, there was neither an overall Simon effect with shape judgments nor a larger Simon effect for active than passive handle state. This result is different from that reported by Tipper et al. in their Experiment 1. However, the absence of Simon effect for those participants who did not view the prior video in our experiment seems to agree with the results obtained in their pilot studies without the video, for which "action affordance effects with the door-handle stimuli were very small" (p. 494). Although Tipper et al. concluded that the video was responsible for the difference in the results that they obtained, our results suggest the possibility that the Simon effect they observed for shape judgments with the video may have been a Type I error. Regardless, the main point is that the lack of difference between the video and no-video conditions in our study provides little evidence that Tipper et al.'s results were a consequence of the video providing a contextual prompt that caused a grasping affordance to be activated. Therefore, the video was not included in the methods of the remaining experiments.

Other studies have suggested that affordances for grasping stimuli can be primed by the task context. Borghi et al. (2007) had participants make left and right keypresses to classify stimuli as natural kinds or artifacts. The stimuli also differed along the irrelevant dimension of the posture typically used to grab the object (precision grip or power grip), and a prime stimulus illustrating a hand in one of the two grips preceded onset of the imperative stimulus. Their Experiment 1 showed no correspondence effect of prime grip and object grip, but their Experiment 2 did show an effect of about 7 ms when the participants performed 15 trials of mimicking each grip at the start of the experiment. Borghi et al. did not report whether this small effect in Experiment 2 differed reliably from the null effect in Experiment 1. Vainio, Symes, Ellis, Tucker, and Ottoboni (2008) did show a strong priming effect, without prior practice, when they used dynamic primes of unfolding grips that remained on the screen after the grip was completed and during presentation of the imperative stimulus.

Note that the priming procedures of Borghi et al. (2007) and Vainio et al. (2008) differ from the procedures of the studies of direct concern in the present paper in that the affordance distinction (precision vs. power grip) has no dimensional overlap with the keypress responses. Thus, any effects would seem to be on identification of the target stimulus, rather than directly on response activation. This was the conclusion reached by Vainio et al. on the basis of their Experiment 2, which showed a similar correspondence effect when the responses were the vocalizations "natural" or "man-made." From this result, they concluded, "Observing an unfolding grasp seems to influence the identification of a target object" (p. 456). Thus, the results of the priming studies do not bear directly on the issue of whether the instructional context influences activation of left and right keypresses to left and right graspable object parts.

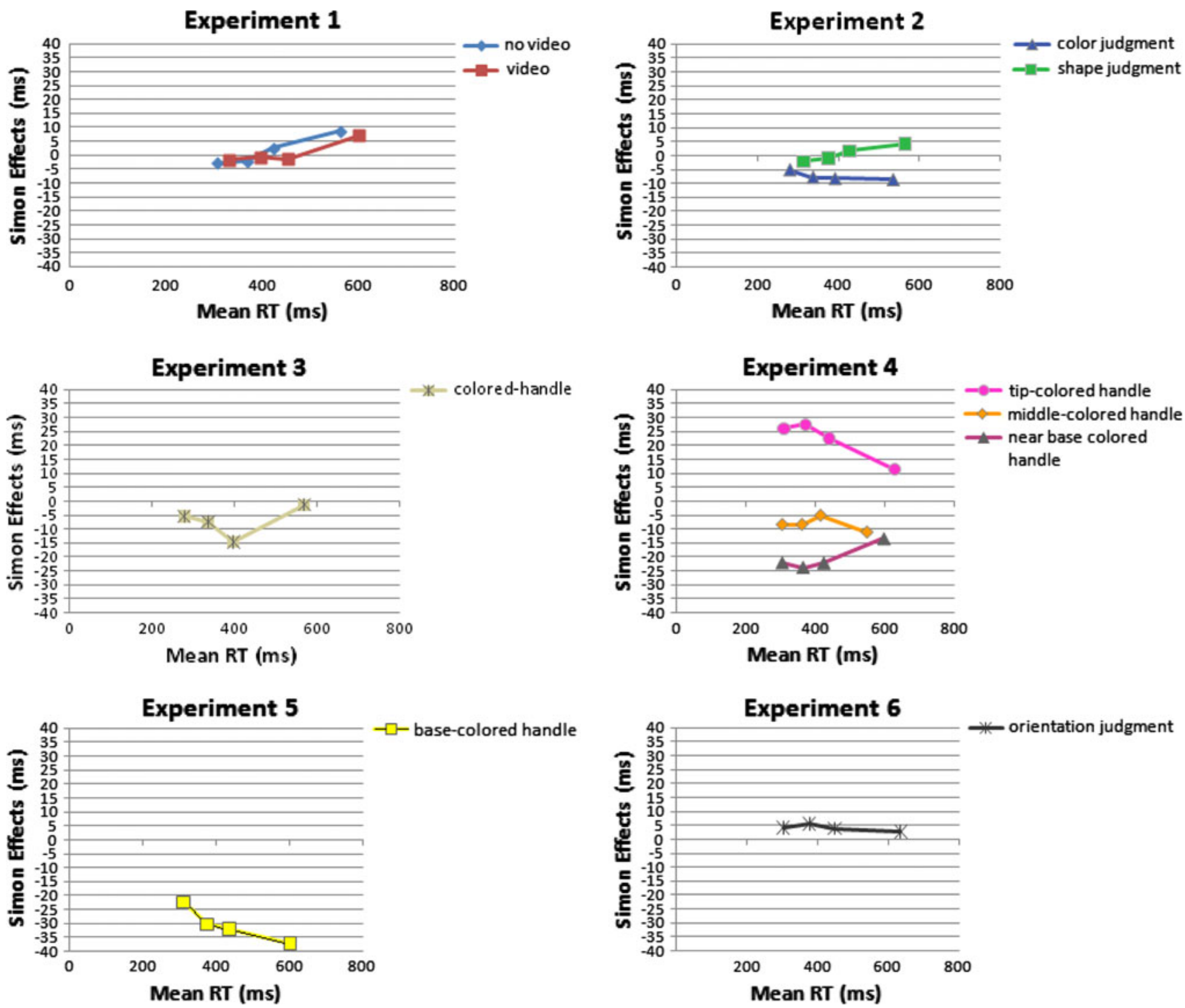

Fig. 3 The Simon effect plotted as a function of the mean RT for each quartile in Experiments 1–6

Experiment 2

Cho and Proctor's (2011) Experiment 4 showed a Simon effect for color judgments relative to the handle for a condition in which the base of the door handle was centered, allowing the handle to vary in location to the left or right. This outcome is consistent with the findings from their experiments in which color or orientation judgments were made to frying pans for which the pan was centered and the handle changed locations (Cho and Proctor, 2010). In contrast, for the condition in which the handle was centered (as for the stimuli used in the present study), and the base varied in left and right locations (see Fig. 1), there was a nonsignificant trend of 9 ms for RT and 0.8 % in PE toward a Simon effect relative to the location of the base.

The size of the nonsignificant Simon effect relative to the base location in Cho and Proctor's (2011) Experiment 4 is similar to that reported for experiments in which participants responded to the red or green color of a centered stimulus in the presence of a simultaneously presented accessory stimulus located to the left or right (e.g., Maetens, Henderickx, & Soetens, 2009). Thus, one purpose of Experiment 2 was to determine whether this Simon effect relative to base location is a reliable phenomenon by testing more than twice as many participants in the color-judgment condition. We also included a shape-judgment condition to replicate the results of Experiment 1 and provide a comparison to those of the color-judgment condition.

Method

Participants

Eighty students[1] (42 males) enrolled in introductory psychology classes who were not in Experiment 1 participated for experimental credits. Forty in the color-judgment condition and 40 in the shape-judgment condition participated for credits toward a course requirement. All had normal or corrected-normal vision and normal hearing.

Apparatus, materials, and procedure

The apparatus and materials were the same as in Experiment 1. Half of the participants were instructed to make a left or right response depending on whether the door handle was green or blue (the color condition), and the other half were told to respond based on whether the door handle was round or square (the shape condition). In other respects, the procedure was the same as the no-video condition of Experiment 1.

Results

Mean RT and PE

The mean RT and PE data are shown in Table 1. The data were analyzed as a function of condition (color, shape) as a between-subjects variable and trial block (first half, second half), action state (active, passive), and correspondence (whether handle side corresponded or not with the location of the correct response) as within-subject variables.

The overall error rate was 1.8 %. Main effects of condition and for RT, Fs(1,78) = 7.42 and 4.60, ps = .008 and .035, $\eta_p^2 = .09$ and .06, but not PE, Fs(1, 78) $\leq$ 1.73. RT was shorter for color judgments (M = 386 ms) than for shape judgments (M = 420 ms), and there was a small Simon effect of −4 ms. Correspondence and condition interacted for both RT and PE, Fs(1,78) = 6.04 and 4.43, ps = .016 and 0.038, $\eta_p^2 = .07$ and .05, respectively. The negative Simon effect was evident for color judgments (–7 ms, –0.5 %), but not shape judgments (0 ms, 0.3 %), indicating a larger influence of the base for color judgments.

The three-way interaction of action state × correspondence × condition was significant for RT, $F(1,78) = 8.81$, $MS_e = 177$, $p = .005$, $\eta_p^2 = .10$, but not PE, $F < 1$. There was a difference in Simon effects for RT between active and passive states for color judgments (active: −2 ms, passive: −13 ms), but not shape judgments (active: −1 ms, passive: 2 ms). For color judgments, state and correspondence interacted for RT, $F(1, 39) = 13.73$, $MS_e = 134$, $p < .001$, $\eta_p^2 = .26$, but not PE, $F(1, 39) = 1.76$, $MS_e = 3.61$, $p = .19$, indicating that the Simon effect was larger for the passive than active state. For the passive state, the Simon effect was significant for RT and PE, Fs(1,39) = 17.39 and 4.73, MS_es = 344 and 5.34, $p < .001$ and $< .05$, $\eta_p^2 = .31$ and .11, whereas for the active state, it was significant for neither measure, Fs < 1. The larger Simon effect for the passive state is most likely due to the base component being more distinctly left or right than when the handle is in the active state. The three-way interaction of trial block, action state and condition was significant for RT, $F(1, 78) = 4.57$, $MS_e = 310$, $p = .036$, $\eta_p^2 = .06$, but not PE, $F < 1$. The other terms, including all that had trial block as a factor, were not significant, Fs < 3.4.

RT distribution analyses

ANOVA of the Simon effect with the four bins and two conditions as factors showed neither a main effect of bin or interaction of bin with condition, Fs < 1.1. The Simon effect did not vary across the RT bins for either condition (see Fig. 3).

Discussion

Consistent with the grasping affordance account, the Simon effects were significantly different for the two judgment types. But, the shape judgments showed no Simon effect, whereas the color judgments showed a Simon effect relative to the left and right base locations. In comparison with Tipper et al.'s (2006) study, the results replicated the difference in Simon effects between color and shape judgments, but not the specific pattern (which, for them, was a Simon effect with respect to handle for shape judgments and no effect for color judgments).

[1] The number of participants was doubled in this experiment. because subsequent experiments were designed based on the results of Experiment 2. Thus, the experiment was conducted originally with 40 participants, and then a replication was conducted with an additional 40 participants to ensure that the main results were reliable. The resulting RT data were analyzed in a single ANOVA of trial block (first half of trial blocks, second half) × state of handle (active, passive) × correspondence (corresponding, noncorresponding) × experiment (original, replication) × condition (color, shape). For this analysis, the only significant term involving experiment was the four-way interaction of trial block × correspondence × condition × experiment, $F(1, 76) = 8.10$, $p = .006$, $\eta_p^2 = .10$. This interaction was due mainly to a somewhat different pattern of results across the two trial blocks for the shape-judgment condition in the two experiments. Because the main results were consistent across the replications, we report the combined data of the 80 participants for Experiment 2.

One difference in the method between our experiment and that of Tipper et al. (2006) that could plausibly have led to the different results is the number of trials, 352 per condition in the present study compared to 128 in Tipper et al.'s study. Simon effects tend to decrease as practice increases (Simon, Craft, & Webster, 1973), which could be a factor in the nonsignificant Simon effect for the shape judgments. Consequently, we included trial block as a factor in Experiment 2, as described in "Results". Although correspondence and trial block did not enter into a three-way interaction with judgment type, the two judgment types showed different patterns. Across the two trial blocks, the Simon effect for RT increased from negative to zero for color judgments, $F(1, 39) = 4.36$, $MS_e = 235$, $p < .05$, $\eta_p^2 = .10$, but it remained at about zero for shape judgments, $F < 1.0$. In other words, for color judgments, early in practice the part of the handle that was physically changing location (the base) produced a Simon effect. But as more trials were performed, the Simon effect decreased, as the location-based Simon effect typically shows (e.g., Simon et al., 1973). For shape judgments, the first trial block, which approximated the number of trials in Tipper et al.'s study, did not show any sign of a Simon effect as a function of the handle, indicating that the number of trials was not the source of the difference.

A second difference between the method of Experiment 2 and that of Tipper et al. (2006) that could have plausibly led to the different results is the separation between response keys. In Experiment 2, responses were made on adjacent keys (*B* and *N*), whereas in Tipper et al.'s experiment responses were made on separated keys (*A* and *L*). To examine this difference, we had 20 additional participants from the same subject pool as in Experiment 1 perform the shape-judgment task, except that responses were made on the *A* and *L* keys of the keyboard (which are separated by seven intervening keys), rather than on the adjacent *B* and *N* keys. The results showed no significant Simon effect for RT or PE, Fs < 1.7 (see Table 1), and the mean differences tended slightly toward negative (−4 ms, –0.1 %). When entered into an ANOVA with the shape judgments of Experiment 2, the experiment (key distance) variable showed no main effect of correspondence or interaction with experiment, Fs < 1.7, indicating that absence of the Simon effect for shape judgments in Experiment 2 was not due to the use of adjacent keys.

Tipper et al. (2006) reported a second experiment, in which shape judgments were made to the stimuli, but with the base of the handle removed so that they appeared as rounded or squared bars. The experiment showed no Simon effect overall and no difference in effect between the active and passive orientations. This result was taken as further evidence for the affordance explanation offered for the interaction that Tipper et al. obtained with the door-handle stimuli. However, two points should be noted. First, although the Simon effect for shape judgments interacted with active versus passive orientation for the handles in Experiment 1 and not the bars in Experiment 2, no between-experiment comparison was reported to confirm that the difference in patterns was statistically significant. Second, it is difficult to know what to make of such a difference, even if significant, given that our results have not replicated the interaction pattern for door-handle stimuli.

A possible basis in processing of integral versus separable dimensions

Having ruled out in Experiments 1 and 2 the most plausible reasons for the difference in results between Tipper et al.'s (2006) study and ours, we decided not to pursue this issue further. Instead, we sought an explanation of the result pattern evident in our experiments: no object-based Simon effect for shape judgments and a Simon effect as a function of the location of the base for color judgments. One possible explanation for the different Simon effects for color and shape judgments in Experiment 2 lies in a distinction between holistic processing of integral dimensions and analytic processing of separable dimensions.

Goodale et al. (Cant & Goodale, 2009; Cant, Large, McCall, & Goodale, 2008; Ganel & Goodale, 2003) provide evidence that shape judgments are based on holistic processing of form that is independent of color processing. Their studies used Garner's (1974) speeded classification task, which measures how fast and accurately participants could process one dimension of an object while ignoring its other dimensions. Cant et al. (2008) had participants make judgments about attributes of computer-generated wooden blocks that differed in width (narrow or wide), length (short or long), color (beige or yellow), and texture (brick or wood). When width judgments were made while length varied randomly or length judgments while width varied randomly, participants were unable to ignore the irrelevant dimension (see also Dykes & Cooper, 1978; Felfoldy, 1974; Ganel & Goodale, 2003; Macmillan & Ornstein, 1998). This outcome of "Garner interference" from the irrelevant size dimension provides evidence that shape is perceived holistically because width and length are dimensions of shape: It is impossible to ignore the length of the object while making width judgments, or vice versa. From these and other results (e.g., Dick & Hochstein, 1988), Cant et al. (2008) concluded, "The evidence that object shape is perceived holistically is overwhelming" (p. 65).

Cant et al. (2008) also examined whether shape processing interacted with processing of color or texture. In contrast to length and width, participants were able to ignore shape while making color or texture judgments and to ignore those properties while making length or width judgments. These results suggest that surface properties such as color are processed independently of shape, whereas the dimensions of shape are processed holistically. More recently, on the basis of brain imaging studies, Cant and Goodale (2011) have concluded that shape and color information is processed by two separate neural substrates in the ventral visual stream: "Specifically, a lateral network involving LO [lateral occipital area] uses surface cues (e.g., texture gradients, specular highlights) to process shape, whereas a medial network involving the CoS [collateral sulcus] and PPA [parahippocampal place area] uses surface cues to process material properties [i.e., texture and color]" (p. 8258).

That judgments related to shape are based on holistic processing whereas color is processed independently from shape suggests that these differences in visual processing, rather than whether or not the judgments are relevant to grasping the object, may be the reason why the object-based Simon effect varies as a function of judgment type. For the door-handle stimuli used in Experiments 1 and 2, in which the handle was centered, the holistic processing of shape should yield little object-based Simon effect because the whole object is centered on the screen every trial, providing little change in left–right location of the object from trial to trial. In contrast, because color is processed independently from form properties, it "pops out" from the display (e.g., Geyer, & Müller, 2009) without requiring shape identification. In this case, the locations of the component features of the stimulus are more critical, and the part of the object that varies in left or right position across trials (the base) should produce a Simon effect relative to its location. That is, the situation is comparable to that of studies that have shown Simon effects of about 10 ms for tasks in which a distinct visual accessory stimulus appears randomly to the left or right of a centered, colored stimulus that designates the correct response (e.g., Maetens et al., 2009; Proctor, Pick, Vu, & Anderson, 2005). Experiments 3–6 had the goal of obtaining additional evidence in support of the integral/separable dimensions hypothesis.

Experiment 3

In Tipper et al.'s (2006) study and Experiment 2, the relevant information for color judgments was distributed across both the base and handle, but the relevant information for shape judgments was limited to the handle (see Fig. 2). An unconfounded comparison requires that the location of the relevant information be consistent for the two judgment types. Moreover, it might be argued that the darker color of the base was responsible for producing the Simon effect relative to the base location (e.g., through drawing attention to the base). To resolve these issues, only the handle component was colored in Experiment 3.

If results similar to those for the shape judgments in Experiments 1 and 2 are obtained for the color judgments, this outcome will suggest that there is no basic difference between the two judgment types. However, if the Simon effects are similar to those for the color judgments in Experiment 2, the conclusion will be that there is a difference between the two judgment types, most likely that color is processed separately from shape. The finding of a Simon effect as a function of the left–right location of the base would be in accord with results from accessory stimulus versions of the Simon task, for which the visual accessory stimulus is achromatic (e.g., Maetens et al., 2009), as the base is in Experiment 3.

Method

Twenty new students (17 males) from the same subject pool as in Experiment 1 participated. The method was identical to that of the color-judgment condition of Experiment 1, except that only the handle was colored, with the base being a neutral gray color (see Fig. 2).

Results

Mean RT and PE

The RT and PE data (see Table 2) were analyzed as a function of trial block, state, and correspondence. The correspondence main effect was significant for RT and PE, Fs(1,19) = 4.54 and 4.85, MS_es = 441 and 4.22, ps < .05, η_p^2 = .19 and .20, yielding Simon effects of –7 ms and –0.7 %. No other effects were significant, Fs < 2.5.

Because Experiment 3 showed small Simon effects similar to those of Experiment 1, the results were compared with those of the color and shape judgments in that experiment. Compared to the color-judgment condition of Experiment 1, no terms interacted with condition, showing similar result patterns, Fs < 2.3. Compared to the shape-judgment condition, correspondence and condition interacted for both RT and PE, Fs(1,58) = 4.51 and 6.34, MS_e = 340 and 259, ps < .05, η_p^2 = .07 and .10, respectively. The Simon effect was more negative for color judgments in Experiment 3 (−7 ms, −0.7 %) than for shape judgments in Experiment 1 (0 ms; 0.3 %). Thus, whether the base was colored mattered little in the results.

Table 2 Mean response times (RT) and percentage errors (PE) as a function of correspondence and action state, and the Simon effect in Experiments 3–6

Experiment	Condition	Action state	Corresponding		Noncorresponding		Simon effect	
			RT (SD)	PE (SD)	RT (SD)	PE (SD)	RT	PE
3	Handle colored	Active	397 (49.02)	2.3 (2.41)	391 (45.27)	1.8 (1.43)	−6	−0.5
		Passive	399 (45.31)	2.4 (1.82)	390 (46.53)	1.5 (1.12)	−9*	−0.9*
4	Tip colored	Active	422 (58.75)	1.1 (0.98)	445 (60.22)	2.5 (2.90)	23*	1.4*
		Passive	426 (63.71)	0.7 (1.07)	446 (53.75)	1.8 (1.41)	20*	1.1*
	Middle colored	Active	409 (62.57)	2.1 (1.68)	401 (63.66)	2.5 (2.92)	−8	0.4
		Passive	414 (60.20)	2.6 (3.30)	406 (60.71)	1.6 (2.17)	−8	−1.0*
	Near the base colored	Active	421 (68.91)	2.3 (2.02)	410 (66.48)	1.8 (1.61)	−11*	−0.5
		Passive	444 (67.33)	3.8 (3.17)	415 (64.59)	1.1 (1.17)	−29*	−2.7*
5	Base colored	Active	438 (76.47)	2.6 (2.38)	421 (72.45)	1.3 (1.76)	−17*	−1.3*
		Passive	455 (72.89)	2.5 (2.60)	411 (67.20)	1.0 (1.63)	−44*	−1.5*
6	Orientation judgment	Active	440 (70.31)	2.7 (2.34)	440 (66.62)	1.8 (1.20)	0	−0.9
		Passive	438 (63.92)	2.8 (2.03)	446 (64.94)	2.7 (1.91)	8	−0.1

* $p < .05$

RT distribution analyses

An ANOVA with four bins as a factor did not show a main effect of bin, Fs(3, 57) = 1.45, $MS_e = 428.19$, $p = .24$, indicating no clear pattern of increasing or decreasing Simon effect across the distributions (see Fig. 3). This flat pattern did not differ from that for color judgments or shape judgments in Experiment 1, Fs < 1.2.

Discussion

The result pattern was similar to that of the color-judgment condition of Experiment 2, again showing a Simon effect relative to the base location. This outcome is in agreement with the view that the Simon effect obtained with color judgments is like that obtained with a separate visual accessory stimulus, which can differ in color from that of the relevant, target stimulus (e.g., Proctor et al., 2005). It is also consistent with the hypothesis that color is processed separately from shape without integrating the base with the handle.

Experiment 4

As shown in Fig. 2, there are multiple places on the handle to which a person could attend when processing color. Consequently, it is unclear from Experiment 3 to which part of the handle participants attended when judging the relevant color information. By restricting the relevant color information to a specific location on the handle (tip, middle, or near the base) for different participants, control over the location to which they must attend for the color judgments can be achieved. When the color appears at the middle of the handle and thus does not change location across trials, a Simon effect should occur as a function of the location of the base (which changes), as for the color judgments in Experiments 2 and 3. The location of the color itself should produce a Simon effect when it always appears at the tip or always near-the-base, because in those conditions its location varies. If the base continues to exert an influence in those situations, the Simon effect should be largest when the color is near the base (and their location codes correspond) than when it is at the tip (and the color location conflicts with that of the base.

Method

Sixty students (35 males), who did not participate in the prior experiments, participated for credits toward a course requirement. All the procedures were identical to color-judgment condition of Experiments 2 and 3 except that only the tip, middle, or base end of the handle was colored. The base component remained in neutral gray color, as in Experiment 3.

Results

Mean RT and PE

The mean RT and PE data are shown in Table 2. The data were analyzed as a function of trial block, action state, correspondence, and condition. The overall PE was 2.0 %.

The only significant term was the correspondence × condition interaction for both RT and PE, $Fs(2,57) = 37.63$ and 12.79, $MS_es = 483$ and 6.24, $ps < .001$, $\eta_p^2 = .57$ and .31. The Simon effects were 21 ms and 1.3 % for the tip-colored condition, −8 ms and −0.3 % for the middle-color condition, and −21 ms and −1.6 % for the near-the-base color condition.

The middle-color condition yielded results similar to those of the color condition in Experiment 1. Compared to the color judgments of Experiment 1, none of the terms interacted with condition, $F < 2.9$. Compared with the shape judgments of that experiment, condition and correspondence interacted for RT, $F(1,58) = 6.32$, $MS_e = 312$, $p = .015$, $\eta_p^2 = .10$, but not PE, $F(1, 58) = 2.49$, $MS_e = 4.15$, $p = .12$, indicating that the middle-color condition (–8 ms) was influenced by the base more than was the shape condition of Experiment 1 (0 ms).

The three-way interaction of trial block, correspondence, and condition was significant for RT, $F(2, 57) = 4.32$, $MS_e = 313$, $p = .02$, $\eta_p^2 = .13$, but not PE, $F < 1.2$. The tip-colored condition showed a larger Simon effect in the first block than in the second block (*M*s = 28 and 15 ms), $F(1,19) = 4.23$, $MS_e = 384$, $p = .05$, $\eta_p^2 = .18$, whereas the Simon effect did not differ significantly across blocks for the middle-color condition (*M*s = −12 and −4 ms), $F(1,19) = 2.23$, $MS_e = 311$, $p = .15$, or near-the-base color condition (*M*s = −24 and −17 ms), $F(1,19) = 1.65$, $MS_e = 245$, $p = .22$. However, all showed a decreasing tendency of Simon effects, if negative Simon effects are considered as "positive" relative to the base location, as typical Simon effects show.

The main effect of state was significant for RT, $F(1,57) = 19.95$, $MS_e = 313$, $p < .001$, $\eta_p^2 = .26$, but not PE, $F < 1$, indicating that RT was shorter when the handle was in an active rather than passive state. The interaction between state and condition was significant for RT, $F(2, 57) = 4.56$, $MS_e = 313$, $p = .015$, $\eta_p^2 = .14$, but not PE, $F(2, 57) = 1.64$, $MS_e = 6.11$, $p = .20$, indicating that the RT difference between active and passive states was different across the conditions: tip colored, 434 ms and 436 ms, $F < 1$; middle colored, 405 ms and 410 ms, $F(1, 19) = 7.44$, $MS_e = 155$, $p = .013$, $\eta_p^2 = .28$; near-the-base colored, 416 ms and 429 ms, respectively, $F(1, 19) = 17.50$, $MS_e = 442$, $p = .001$, $\eta_p^2 = .48$. State and correspondence interacted for PE, $F(1,57) = 10.44$, $MS_e = 4.60$, $p = .002$, $\eta_p^2 = .16$, but only marginally for RT, $F(1,57) = 2.97$, $MS_e = 469$, $p = .09$, $\eta_p^2 = .05$, indicating the Simon effects for the passive state tended to be more negative than the active state (active state: 0 ms, 0.5 % passive state: –6 ms, –0.9 %).

Although the three-way interaction of correspondence and state with condition was not significant for RT or PE, $Fs(1,57) = 2.06$ and 2.04, $ps = .14$, a difference between Simon effects between active and passive states was not evident for the tip-colored and middle-color conditions, $Fs < 1.0$, but was for near-the-base condition. For the latter condition, state and correspondence interacted for both RT and PE, $F(1,19) = 10.86$, $MS_e = 297$, $p < .005$, $\eta_p^2 = .36$, indicating a larger negative Simon effect for the passive state (−29 ms, −2.7 %) than for the active state (−11 ms, −0.5 %). The Simon effect for the passive state (level handle) was significant for both RT and PE, $Fs(1,19) = 43.58$ and 15.29, $MS_es = 401$ and 9.09, $ps < .001$ and .002, $\eta_p^2 = .45$, whereas that for the active state was significant for RT, $F(1,19) = 11.00$, $MS_e = 370$, $p < .005$, $\eta_p^2 = .37$, but not PE, $F(1,19) = 1.23$, $MS_e = 4.84$, $p = .28$.

RT distribution analyses

ANOVA of the Simon effect with the four bins and three conditions as factors was performed. This ANOVA did not show a main effect of bin, $F < 1$, but the two-way interaction of bin and condition was significant, $Fs(6, 171) = 2.95$, $MS_e = 260$, $p = .009$, $\eta_p^2 = .09$ (see Fig. 3). For the middle-color condition, the Simon effect did not vary as function of bin, $F < 1$, similar to Experiments 1 and 2. For the tip-colored condition, in contrast, the Simon effect decreased across the RT distribution, $Fs(3, 57) = 3.90$, $MS_e = 277$, $p = .013$, $\eta_p^2 = .17$, as standard Simon effects typically do (e.g., Proctor et al., 2011). The near-the-base condition showed a nonsignificant tendency for the negative Simon effect to move closer to zero as RT increased, $F(3,57) = 1.33$, $MS_e = 340$, $p = .27$. In fact, when it was analyzed with the tip-colored condition, there was no main effect of bin, $F < 1$, indicating that the two functions canceled each other out (i.e., the Simon effect functions were similar, but in opposite directions).

Discussion

The middle-colored handle, for which the color did not change position on the screen from trial to trial, showed a Simon effect relative to the base location, and the overall size of the effect was similar to those of Experiments 2 and 3. This result is consistent with the conclusion from the earlier experiments that, when the color is in a fixed location on every trial, the Simon effect is a consequence of the base being coded as left and right.

In contrast, the tip-colored handle showed Simon effects relative to the handle location, rather than the base. Also, the RT distribution for the tip-colored condition showed the Simon effect to decrease as RT increased, similar to the standard Simon effect (e.g., green/red circle appearing in left/right spatial locations; e.g., De Jong et al., 1994). This decreasing pattern indicates greater variability for corresponding trials than for noncorresponding trials (Zhang & Kornblum, 1997), possibly due to rapid activation of the corresponding response, followed by dissipation of that activation (e.g., De Jong et al., 1994). That the results for tip-colored condition were similar to those of the standard Simon effect should not be too surprising, because the location of the relevant stimulus color varied between left and right positions on the screen. The results for the tip-colored condition are similar to the findings of Iani, Baroni, Pellicano, and Nicoletti (2011), who required participants to judge the upright/inverted orientation of graspable objects shown to the left or right of fixation, with the graspable part oriented to the right or left. Their results showed that when the object location and response position corresponded, performance was faster and more accurate irrespective of handle position. Thus, consistent with the tip-colored handle in the present study, the location of the relevant information was a major factor contributing to the Simon effect, regardless of the position of the object part, the base.

The near-the-base condition showed a Simon effect of similar size to that found when the color was at the tip. Also, the distribution functions for those conditions did not differ, when direction of effect (away from or toward the base) was taken into account. These similarities in effect sizes implied that the base did not influence performance in the tip-colored condition because, if it did, the Simon effect would be smaller for that condition in which the base opposed the color location than for the near-the-base condition in which the locations corresponded.

For the near-the-base condition, the Simon effect was larger for the passive than active state, implying that the left versus right position of the base was more distinct when the door handle was displayed horizontally rather than diagonally. This difference in Simon effects for active and passive states when making color judgments was also evident in Experiment 2, and Experiment 3 showed a similar, nonsignificant tendency: comparison of those two conditions with the near-the-base condition of Experiment 4 showed significant correspondence × state interactions for both RT and PE, $Fs(1,77) = 16.99$ and 10.88, $MS_es = 225$ and 3.59, $ps < .001$, $\eta_p^2 = .18$ and .12, but the three-way interactions with experiment were not, $Fs(2,77) = 2.39$ and 2.78, $ps = .10$ and .07. The absence of influence of active versus passive state for the tip-colored and middle-color conditions of Experiment 4 implies that handle state matters only when the region of the handle that is colored overlaps with the base component. In other words, the difference between two action states might occur when the relevant information overlaps with the base. To test this hypothesis, only the base of the door handle was colored in Experiment 5.

Experiment 5

The Simon effect for the passive state was larger than that for the active state in the color-judgment condition of Experiment 1 and the near-the-base color condition of Experiment 4. To confirm the hypothesis that larger Simon effects for the passive state are due to the fact that the relevant information overlaps with the base, only the base component was colored (see Fig. 2).

Method

Twenty students (16 males), who did not participate in previous experiments, participated for credits toward a course requirement. The method was identical to the color-judgment condition of Experiment 1 except that only the base component of the door handle was colored; the handle component had a neutral gray color (see Fig. 2).

Results

Mean RT and PE

The mean RT and PE data are shown in Table 2. The data were analyzed as a function of trial block, state, and correspondence. The overall PE was 2.2 %. The main effect of correspondence was significant for RT and PE, $Fs(1,19) = 30.20$ and 21.52, $MS_es = 1,240$ and 3.64, $ps < .001$, $\eta_p^2 = .61$ and .53, yielding Simon effects of −31 ms and −1.4 %.

State and correspondence interacted for RT, $F(1,19) = 23.76$, $MS_e = 321$, $p < .001$, $\eta_p^2 = .56$, but not PE, showing a larger negative Simon effect for the passive state (passive state: −44 ms) than for the active state (active state: −17 ms). The Simon effect for the passive state was significant for both RT and PE, $Fs(1,19) = 84.80$ and 8.29, $MS_es = 465$ and 5.79, $p < .001$ and $p = .01$, $\eta_p^2 = .82$ and .30. For the active state, the Simon effect was also significant for both RT and PE, $Fs(1,19) = 5.15$ and 7.56, $MS_es = 1,096$ and 4.13, $ps = .035$ and .013, $\eta_p^2 = .21$ and .28.

The pattern of results with the base colored in this experiment was not different from that for the near-the-base color condition of Experiment 3 (action state × correspondence × experiment) was not significant either for RT, $F(1,38) = 1.51$, $MS_e = 309$, $p = .23$, or PE, $F(1,38) = 3.12$, $MS_e = 5.43$, $p = .09$. All other terms were not significant, $F < 2.5$.

RT distribution analyses

An ANOVA of the Simon effect with the four bins as a factor did not show a main effect of bin, $F < 1.1$,

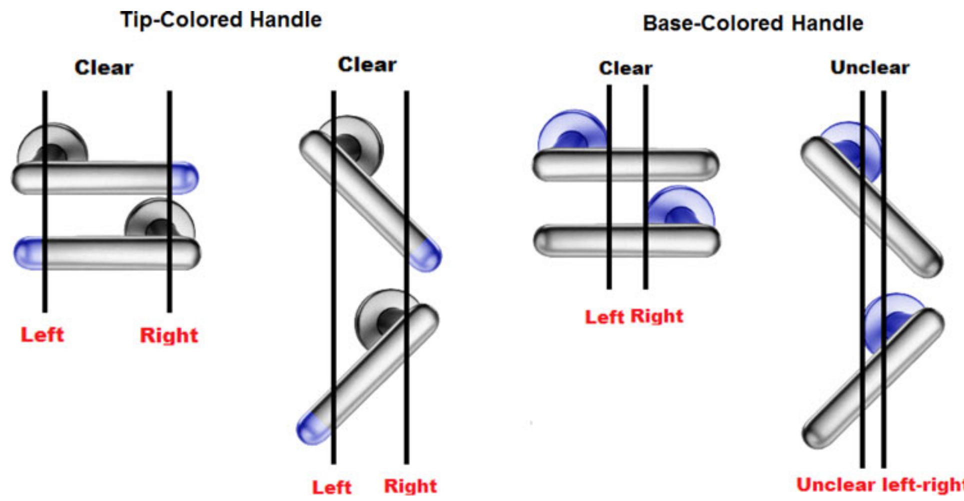

Fig. 4 Basis of larger Simon effects for passive than active state

indicating no clear increasing or decreasing pattern across the RT distributions. In comparison with the near-the-base colored in Experiment 3, an ANOVA did not show either a main effect of bin, $F < 1$, or a two-way interaction of bin with condition, $F(3,114) = 1.85$, $MS_e = 539$, $p = .14$. The Simon effect did not increase or decrease across the RT bins for both conditions, showing similar patterns (see Fig. 3).

Discussion

Larger Simon effects were obtained for passive than active states, consistent with the color-judgment condition of Experiment 2 and the near-the-base color condition of Experiment 4. The results confirm that the larger Simon effect for the passive state is due to the relevant information being located at the base component and not to a grasping affordance. But what is special about the base component that causes larger Simon effects for the passive state? As shown in Fig. 4 (right side), left–right location for the base component is more distinct for the passive than active state, whereas in the tip-colored condition of Experiment 4 (left side of the figure), for example, the left and right locations are distinct for both active and passive states.

Experiment 6

The overall Simon effect for shape judgments in Experiments 1 and 2 was different from that for color judgments in the other experiments, and none of the color-judgment conditions in Experiments 2–5 yielded an absence of Simon effect as the shape judgments did. These results are in agreement with the hypothesis that color is a separable dimension from shape, but shape is an integral dimension that requires holistic processing of an object. The purpose of Experiment 6 was to obtain converging evidence that the object-based Simon effect is absent when processing is holistic by using another task for which the judgments should be based on holistic processing. According to Cant et al. (2008, p. 65), “It is impossible to attend to one dimension, such as width, while ignoring another, such as length (indeed, other dimensions of object shape, such as orientation and the length of lines, have also shown Garner interference; see Dick and Hochstein 1988).” Consequently, in Experiment 6 we required participants to judge another dimension of object shape, orientation of the door handle. The prediction was that because object orientation is processed holistically as an integral dimension of shape, there should be no Simon effect, either for the passive or active handle state.

Method

Twenty new students from the same pool as in previous experiments participated. All the procedures were identical to Experiment 1 except judgment type: Participants were instructed to judge the orientation (horizontal/diagonal) of the door handle (which corresponds to the passive/active distinction; see Fig. 2).

Results

Mean RT and PE

The mean RT and PE data are shown in Table 2. The data were analyzed as a function of trial block, state, and correspondence. The overall error rate was 2.5 %. The main effect of correspondence was not significant for RT or PE, $Fs(1,19) = 1.40$ or 2.01, $MS_es = 452$ and 5.21, $p = .25$

and .17, respectively, yielding Simon effects of 4 ms and −0.5 %. All other terms were not significant, Fs < 3.0.

Because the present experiment showed negligible overall Simon effects similar to those of Experiment 1, they were compared with color and shape judgments in that experiment. Compared with the color-judgment condition, correspondence and condition interacted for RT, $F(1,58) = 6.75$, $MS_e = 514$, $p = .012$, $\eta_p^2 = .10$, but not for PE, $F < 1$, indicating larger Simon effects relative to the base direction for the color condition of Experiment 1 than for the orientation judgments of this experiment. Compared with the shape-judgment condition, however, correspondence and condition did not interact either for RT, $F < 1$, or PE, $F(1,58) = 3.81$, $MS_e s = 4.78$, $p = .06$, indicating similar size of Simon effects for RT, whereas the Simon effects for PE tended to show difference for both conditions (shape judgment: 0.3 %, orientation judgment: –0.5 %) though the difference was less than 1 % numerically.

RT distribution analyses

An ANOVA of the Simon effect with the four bins did not show a main effect of bin, $F < 1$, indicating no clear pattern of increasing or decreasing across the RT distributions. Compared with the color judgments of Experiment 1, the two-way interaction of bin and condition was not significant, $F < 1$. Compared with the shape judgments of Experiment 1, the two-way interaction of bin and condition was not significant either, $F < 1$ (see Fig. 3). All conditions showed no changes of Simon effects across the RT distributions.

Discussion

The Simon effects were absent for orientation judgments, as predicted on the basis of such judgments seeming to require holistic processing of the object shape. A nonsignificant 4-ms Simon effect was obtained relative to the handle direction. Pellicano et al. (2010) also found an overall Simon effect of 5 ms, but significant, relative to the handle direction when upright/inverted orientation of a flashlight was judged. Similar to the results of the present study, they found a significant 10-ms Simon effect relative to the side opposite to the handle when color was judged (present study: 7 ms, significant).

Although the Simon effect was not significant in Experiment 6, the overall results are similar to those of Pellicano et al. (2010): a negative Simon effect was obtained when color was judged (opposite side of the handle), and the overall size of the Simon effect for orientation judgments was numerically similar to their study, yielding only 1-ms difference in mean value from the present study. Because the Simon effects were not significant relative to the handle and there was no difference in Simon effects between active and passive states, grasping affordance cannot easily explain the present results. The nonsignificant Simon effect for orientation judgments is more consistent with holistic processing, suggesting no clear left–right distinction.

Compared to the shape-judgment condition of Experiment 1, the two-way interaction of correspondence and condition was not significant for RT. Moreover, none of the variables interacted with condition, indicating that the results of orientation judgments were similar to those of the shape judgments. Both yielded an absence of Simon effects, suggesting there is no distinct left–right location. This result is counter to the grasping affordance account, which predicts a Simon effect relative to handle direction. That the Simon effect was no larger for the active than passive state suggests no effect of grasping affordance according to their framework.

One might argue that absence of Simon effects is due to the longer mean RTs for shape and orientation judgments than for the other conditions. In opposition, the Simon effects were absent even with the fastest RTs for both shape and orientation judgments (see Fig. 3).

General discussion

The present study sought to determine the basis for differences in object-based Simon effects for action-relevant and action-irrelevant judgments obtained with keypress responses to stimuli that do not have an obvious laterality component (door handles presented with the handle centered). It has been argued that for action-relevant judgments grasping affordances are activated that result in a correspondence effect (i.e., Simon effect) for the handle location with that of the responding hand (Loach et al., 2008; Pellicano et al., 2010; Tipper et al., 2006). Yet, in Experiments 1, 2, and 6, we found no Simon effect for shape judgments or orientation judgments, both of which are action relevant. Also, there was no interaction of active versus passive handle state, whereas larger effects for active than passive states have previously been taken as evidence for a grasping affordance (Pellicano et al., 2010; Tipper et al., 2006).

In contrast, in Experiments 2 and 3, color judgments showed a Simon effect relative to the location of the base of the handle, which is the part that was varying in left and right physical locations: RT was shorter when the response location corresponded to that of the handle's base than when it did not. This result was obtained regardless of whether both the handle and base were colored (Experiment 2) or only the handle (Experiment 3). Our results with color judgments conform to those of studies that required participants to judge the color of a centered stimulus flanked by an irrelevant accessory stimulus, which varied in left and right position from trial to trial (e.g., Maetens et al., 2009; Proctor et al., 2005). Those studies found 10-ms Simon effects relative to the location of the accessory stimulus. Although Tipper et al. (2006) did not find any Simon effect for color judgments, Pellicano et al. (2010) did obtain a pattern similar to ours of a Simon effect relative to the changing location of the light-emitting end of a flashlight.

On the whole, the results of Experiments 1–3 confirm differences in Simon effects for keypress response selected on the basis of object properties relevant to action (form and orientation) and color. However, they provide no indication that those differences are due to grasping affordances that are activated for shape judgments, but not color judgments.

The details of our results for Experiments 1–3 do not match those of Tipper et al.'s (2006) experiment. Whereas they found Simon effects relative to the handle (left or right facing) for both active and passive handle states with shape judgments, but no Simon effects with color judgments, we found no Simon effects with shape judgments but Simon effects of 10 ms relative to the base location with color judgments. We used the same stimuli in Experiments 1 and 2 as Tipper et al. did, so the difference in result patterns must have some other basis. We considered three plausible methodological factors that could account for the difference in results. Our Experiment 1 provided evidence that a prior video is needed to prime the grasping affordance, showing a similar absence of Simon effect for shape judgments when an instructional video demonstrating handle operation was used and when it was not. Although our experiment included twice as many trials overall as Tipper et al.'s, we showed that similar results were obtained in the first and second halves of Experiment 2. Finally, we described an additional condition in which we obtained similar results for shape judgments with separated response keys, like Tipper et al. used, as with adjacent ones. Exactly why Tipper et al.'s results and ours differ remains an unanswered question, but after considering several plausible reasons for the difference, we decided to pursue the consistent pattern of results obtained in our experiments, testing implications of the hypothesis that it reflects a distinction between judgments based on holistic versus analytic processing of the visual stimuli.

In Experiment 4, the relevant color information was localized to a specific region of the handle (tip, middle, or near the base). When the middle of the handle was colored (and the color appeared at a constant location across trials), Simon effects relative to the base location were evident, as in the color conditions of Experiments 2 and 3, indicating that the base was being coded as left or right. However, when the tip or an area of the handle near the base was colored (and, consequently, the position of the color varied as a function of whether the handle faced left or right), the Simon effect was obtained relative to the color location, as with a standard Simon task. That is, when the color was at the handle tip, responses were faster and more accurate when the base location did not correspond with the response (but the color location did), whereas when the color was near the base, responses were faster and more accurate when the base location (and color location) corresponded with the response. Moreover, the size of the Simon effect was as large for the tip-colored condition as for the near-the-base color condition, implying that the opposing location of the base in the tip-colored condition did not influence performance. Such an outcome is consistent with accounts of the Simon effect and reductions of the Stroop color-naming effect caused by an additional neutral word that emphasizes shifts of attention (e.g., Cho, Choi, & Proctor, 2011; Rubichi, Iani, Nicoletti, & Umiltà, 1997): In the tip-colored condition, attention would be captured by the tip location to process the color, resulting in the base location having no impact on performance.

Neither the tip-colored condition nor middle-color condition of Experiment 4 showed a difference in Simon effects between passive and active handle states, whereas the conditions of Experiments 2 and 3 in which the handle was colored and the near-the-base color condition of Experiment 4 showed a larger Simon effect passive than active states that did not interact significantly with experiment. These results imply that handle state matters when the colored region overlaps with the base of the handle, which may direct attention more to the base. As illustrated in Fig. 4, because the location of the base is closer to the center when the handle is in the active position than when it is in the passive position, the base is more likely to be coded as left or right with the handle in the passive state. In Experiment 5, the relevant color information was confined to the base, and the Simon effect again was larger for the passive state than for the active state. That the influence of handle state on performance was restricted to conditions in which color was relevant and not shape or orientation, and was in agreement with what would be expected on the basis of coding of the handle location as left or right.

Experiment 6 confirmed that the absence of Simon effect obtained with shape judgments in Experiments 1 and 2 generalizes to another object-based property, judgments of horizontal versus diagonal orientations of the door handles. This result provides converging evidence to suggest that little Simon effect is obtained when judgments are based on holistic processing of the objects. On the whole, the combined results of all six of our experiments are in accord with a spatial coding account that distinguishes analytic from holistic processing.

At first glance, it may seem that the results of the present study are inconsistent with the experiments using frying pan and teapot stimuli in Cho and Proctor's (2010, 2011) studies, because in them the Simon effects for color judgments were not different from the effects for upright-inverted orientation judgments. It should be kept in mind, though, that in those studies the stimuli were presented with the base (body) of the pan or the pot centered on the screen, which allowed the handle to appear in left or right locations on the screen. This is in contrast to the present experiments, in which the handle was centered (as was the entire object).

In particular, comparison with Cho and Proctor's (2010) study is informative because the frying pan stimuli used in it are similar to the door-handle stimuli: Both have a round part to which the handle is attached (body of the frying pan, base of the door handle) and an elongated handle. The critical difference in stimulus presentation was that the relevant information (handle) of the frying pan was randomly varied in the left and right position because the pan was centered, whereas that of the door handle did not change in the present experiments because the handle was centered. In other words, if the relevant information which people judge varies in left and right positions, a sizeable Simon effect is obtained, as in the frying pan study. Because the center of the whole object, as well as the location, varied as a function of the side to which the handle was attached, the type of judgment had little effect. Likewise, in the study of Riggio et al. (2008), substantial object-based Simon effects relative to the handle location were obtained in Experiments 1 and 2, in which the bodies of the objects were centered along the vertical axis of the display. In contrast, those same objects produced only an object-based Simon effect "very small in magnitude" (p. 456) when they were positioned to the left and right on the display. Perhaps most convincing, the door-handle stimuli that yielded either no Simon effect or a negative Simon effect relative to the handle when the handle was centered, as in the present experiments and Tipper et al.'s (2006) study, showed a positive Simon effect of 30–40 ms when the base of the handle was centered and the handle shown to the left or right side (Cho & Proctor, 2011, Experiment 4; Galpin et al., 2011).

Compared to Cho and Proctor's (2010) study with the frying pan stimuli, the Simon effects for stimuli without an obvious laterality component in the present experiments were much smaller. Whereas for the frying pan stimuli the overall Simon effect was 38 ms, in Experiment 2 of the present study the overall Simon effect was negligible (−4 ms). The color-judgment results from our current study are similar to those of Pellicano et al.'s study in showing 10-ms Simon effects relative to the side opposite the handle (the base in our experiment and the light end of the flashlight in theirs). However, for orientation judgments, Pellicano et al. reported a small, but significant, 10-ms object-based Simon effect relative to the graspable end of the flashlight when in the active state but not when it was in the passive state, a finding that does not match our results.

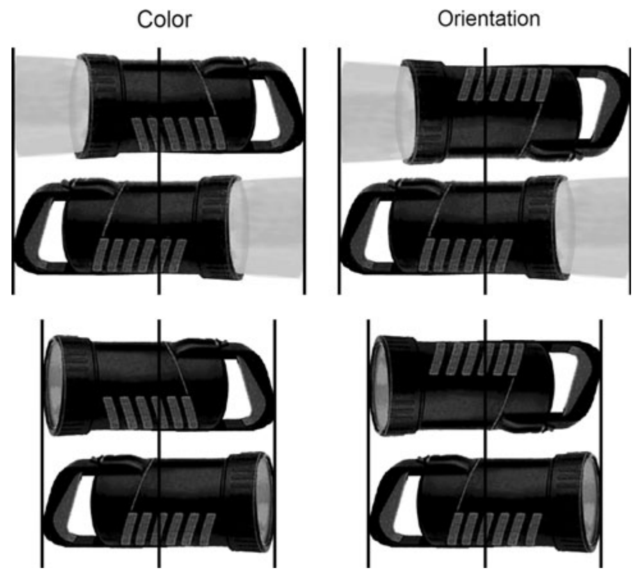

Fig. 5 Flashlight stimuli used for Pellicano et al.'s Experiment 1 (presented in *red* or *blue* color for color judgments) and Experiment 2 (orientation judgments), with vertical lines added to mark the center and extent of the displayed stimuli. Adapted by Pellicano et al. (2010) (color figure online)

Pellicano et al.'s (2010) stimuli (see Fig. 5) included additional features that could have influenced their results: the handle was slanted and the flashlight contained six strips of lighter contrast on the body with the same slant as the handle. For the color-judgment experiment (left side), the flashlight was always in an upright orientation, with the strips located at the bottom of the image and irrelevant to the required judgment. In contrast, for the orientation-judgment experiment (right side of Fig. 5), the flashlight was in an upright orientation on half of the trials and an inverted orientation on half. As a consequence, the position of the strips in the upper or lower part of the image varied and was a relevant cue for the required judgment. Both the varying position of the strips vertically and their location being relevant to the task would cause them to be weighted more in the decision process (Memelink & Hommel, 2012; Yamaguchi & Proctor, 2012). Crucially, the position of the row of strips to the left or right of display center corresponded to the left or right location of the handle. Because the entire display was centered, this left–right position difference of the strips was larger when the light was in an active state rather than a passive one. Thus, the Simon effect for the active-state stimuli in Pellicano et al.'s study could have been due to spatial coding of the location of the row of strips and not to the handle affording grasping.

Concluding remarks

Bub and Masson (2010) distinguished two types of object-based compatibility effects:

> One type involves hand action representations associated with reaching and grasping the handle of an object; if the handle is aligned with the response hand, then responses are faster than when the opposite response hand is used. Other compatibility effects induced by handled objects do not clearly reflect the evocation of reach and grasp representations, but instead involve more abstract spatial codes activated by the orientation of an object that affect any left–right response discrimination (e.g., index vs. middle finger of the same hand). (p. 341).

Previously, we have shown that when the non-graspable part of an object is centered and the graspable part occurs in a left or right position, compatibility effects are obtained with keypresses that can be attributed entirely to the second type identified by Bub and Masson (e.g., they are obtained with the index and middle finger of a single hand, as well as with the index fingers of each hand). For displays in which the entire object is centered, as in the present study, Bub and Masson found object-based compatibility effects when the decision required a reach-to-grasp response with the left or right hand but not when it required a keypress, also implying no role of the first, grasping affordance type of compatibility effect with keypresses. The results of the present experiments also show no indication of a contribution of affordance compatibility, only Simon effects in some conditions due to spatial coding. Between their study and ours, there is no sign of a grasping affordance affecting performance when the responses are keypresses.

Largely because of Tipper et al.'s (2006) finding of object-based Simon effects for shape judgments paired with keypresses when participants first viewed a video illustrating operation of handles, Bub and Masson (2010) conjectured that affordances may influence keypress responses when there are prior contextual prompts. Yet, our Experiment 1 did not show a Simon effect even after viewing a similar video, suggesting that this disclaimer is not needed. More generally, the majority of evidence indicates that compatibility effects obtained with keypresses to graspable objects are due primarily, if not solely, to the second of Bub and Masson's types, location coding of the kind that underlies other spatial compatibility effects, and not to representations that afford grasping.

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