Effects of Irrelevant Stimulus Orientation on Visually Guided Grasping Movements

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The present study investigated the effects of irrelevant stimulus orientation on visually guided grasping movements. Participants had to grasp a rectangular object at either the ends or the sides, depending on the color of a visual stimulus. In this task, correspondence between stimulus orientation and object orientation (stimulus–object congruency) and correspondence between stimulus orientation and hand orientation (stimulus–hand congruency) varied independently. Two experiments, with different sets of object orientations, revealed a consistent pattern of results. In particular, there were significant effects of stimulus–hand congruency, suggesting that perceiving an object activates congruently oriented hand movements. However, stimulus–object congruency had no effects, indicating that participants did not benefit from a preactivation of object orientation in the present task. The pattern of congruency effects implies that the cognitive representation, which is affected by irrelevant visual information, entails only those object or response features that are needed to select and control a response.

Keywords: grasping, hand orientation, object orientation, stimulus–hand congruency, stimulus–object congruency

Many human actions are directed toward objects in three-dimensional space. While acting on these objects, our visuomotor system has to take into account several spatial features of the objects, such as their location and orientation. This suggests the possibility that spatial object features might have direct access to the motor system. In other words, the importance of spatial object features for action control suggests the existence of “privileged loops” (McLeod & Posner, 1984) for the processing of such features. In fact, some behavioral observations are consistent with the idea that spatial object features might have direct access to the motor system.

The well-known Simon effect (Simon & Rudulff, 1967; see also Hedge & Marsh, 1975) suggests that the act of perceiving the location of a stimulus can directly activate spatially corresponding response codes. In a typical Simon task, participants have to respond to a nonspatial stimulus feature by performing a spatially defined response (e.g., pressing a left key to a green stimulus and pressing a right key to a red stimulus). It is important that horizontal stimulus location varies randomly from trial to trial, although it is irrelevant for the task at hand. The interesting result is that spatially corresponding conditions (e.g., green stimulus at left location) produce shorter reaction times (RTs) than spatially noncorresponding conditions (e.g., green stimulus at right location; see Lu & Proctor, 1995, for a review). Typical explanations for the Simon effect involve two parallel routes for stimulus–response (S–R) processing (e.g., Kornblum, Hasbroucq, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999). In particular, it is assumed that the response to the nonspatial stimulus feature (e.g., color) has to be computed through an indirect route, in a controlled mode of processing. In contrast, stimulus location is assumed to activate a spatially corresponding response through a direct route, in an automatic fashion. In corresponding conditions, the outputs of both routes match, which facilitates execution of the correct response. In contrast, in noncorresponding conditions, the outputs do not match, and a response conflict delays responding.

The dual-route models proposed to explain the Simon effect (e.g., Kornblum et al., 1990) resemble the distinction between two visual processing pathways that has been made in neuropsychological and neurophysiological research (e.g., Goodale & Milner, 1992; Rumiati & Humphreys, 1998). A ventral pathway of visual processing expands from the occipital lobe to temporal cortical areas. This pathway is assumed to be involved in the classification and identification of objects and in the construction of a conscious representation of the visual world (“vision for perception”). Additionally, a dorsal pathway of visual processing expands from the occipital lobe to the posterior parietal cortical areas. This pathway appears to control skilled actions, such as grasping (“vision for action”). Studies on patients with brain lesions have revealed a double dissociation between the functions of the two pathways: Patients with lesions of the ventral pathway usually can grasp objects, although they fail to identify them (e.g., Goodale, Milner, Jakobson, & Carey, 1991; Riddoch & Humphreys, 1987). Patients with lesions of the dorsal pathway typically identify seen objects but are unable to perform visually guided grasping movements (e.g., Jakobson, Archibald, Carey, & Goodale, 1991). In some...
cases, these patients can gesture in response to an object’s name, indicating that intact access of semantic knowledge through the ventral pathway is allowing them to select object-directed actions (e.g., Riddoch, Humphreys, & Price, 1989). Like the models explaining the Simon effect, neuropsychological models assume the existence of both a direct and an indirect route (via the dorsal and the ventral pathway, respectively) from perception to action.

Recent behavioral research by Craighero and colleagues (Craighero, Fadiga, Rizzolatti, & Umiltà, 1998; Craighero, Fadiga, Umiltà, & Rizzolatti, 1996) has suggested that perceiving the (task-irrelevant) orientation of a visual stimulus can directly activate congruent response codes. In these experiments, participants had to grasp a bar that was tilted either 45° to the left or 45° to the right with respect to the sagittal plane of the participant’s body. The object had to be grasped at the ends without being visible, but participants were informed about object orientation before movement execution, so the movement could be prepared for in advance. The prepared grasping movement had to be executed as quickly as possible on the presentation of a visual go signal. Briefly before, simultaneously with, or shortly after the go signal, a prime stimulus was presented. The prime stimulus was a rectangular shape that could be oriented congruently or incongruently to the orientation of the to-be-grasped bar, and there was a neutral condition as well, in which a circle was presented. The important result was that a congruently oriented prime stimulus appearing shortly before the go signal facilitated the initiation of the prepared grasping movement, although the prime was irrelevant for the task at hand. Craighero et al. (1996, 1998) referred to this observation as a visuomotor priming effect (for related findings, see Bridge- man, 2002; Creem & Proffitt, 2001; Tucker & Ellis, 1998, 2001, 2004). In particular, they concluded that “seeing an object facilitates an action congruent with the visual properties of that same object” (Craighero et al., 1998, p. 120).

Subsequent studies provided additional support for the notion that irrelevant grasp-related object features, such as location, orientation, or size, can affect the performance of grasping actions. For example, Tucker and Ellis (2001) asked participants to categorize visually presented objects as either natural or man-made by making a precision grip (i.e., opposing the thumb and index finger) for one category and making a power grip (i.e., grasping with the whole hand) for another category. The results showed that the size of the objects, which was irrelevant for the task, affected the responses: If the object category required a precision grip, responses were faster to small objects as compared with large. Similarly, power grips were faster to large objects as compared with small. Thus, correspondence between the classification response and object size produced faster responses than did noncorrespondence. Furthermore, Edwards, Humphreys, and Castiello (2003) observed that participants adapted grip aperture to the size of a disk more quickly after movement initiation when they had seen the same object prior to the movement, as compared with conditions in which they had seen an object of different size. These studies may be taken as evidence that observation of an object preactivates spatially corresponding response codes and that this priming subsequently helps to initiate and execute a corresponding movement. Such visuomotor priming effects are typically attributed to a direct route from vision to action that bypasses a semantic representation (e.g., Jeannerod, 1997; Rumiati & Humphreys, 1998) and that may be mediated by the dorsal pathway of visual processing (e.g., Goodale & Milner, 1992).

Cant, Westwood, Valyear, and Goodale (2005) have recently challenged the claim that priming of visually guided grasping movements can occur through the dorsal pathway. These authors defined “true” priming as “the re-activation of representations of objects or actions laid down earlier” (p. 217). In their view, previous exposure to the goal object should have little effect on the programming of grasping movements because the visual control of action through the dorsal pathway should work in real time (“real-time view of motor programming”; see also Goodale, Westwood, & Milner, 2004). Hence, Cant et al. attributed the priming effects observed by Craighero and colleagues (1996, 1998) to the fact that online visual information about the target object was not available for movement control in the Craighero task. Hence, participants had to rely on a memory representation of the target object instead, a task that presumably involved the ventral pathway. In three experiments, Cant et al. tested whether previous exposure to congruently or incongruently oriented objects could prime the initiation of grasping movements performed under full visual control. To test true priming, these authors used much longer stimulus onset asynchronies (1,750, 2,000, or 2,250 ms) between the prime stimulus and the go signal than those used by Craighero et al. (100 ms). Under these conditions, neither the opportunity to view the target object nor the opportunity to grasp it had any effect on subsequent grasping movements. Thus, Cant et al. concluded that priming of grasping movements via the direct (i.e., dorsal) pathway is not possible and that the priming effects observed by Craighero and colleagues are restricted to memory-guided actions, which depend on the ventral pathway.

The purpose of the present study was to explore whether irrelevant spatial information presented simultaneously with a go signal could affect visually guided grasping movements. According to the real-time view of motor programming (Goodale et al., 2004), the coordinates of a grasping movement are computed immediately before the movement is initiated. However, the question was whether these coordinates are specified only by the to-be-grasped object or whether other spatial information (e.g., the irrelevant orientation of the go signal) can also affect movement programming and execution. In particular, we investigated the impact of irrelevant stimulus orientation on the processing of two aspects of a visually guided grasping movement: (a) the orientation of the grasping hand and (b) the orientation of the to-be-grasped object. The orientation of the grasping hand was varied with regard to an imaginary line between the thumb and index finger (Mamassian, 1997).

In our task, the color of a visual stimulus instructed participants to grasp a visible rectangular bar (see Figure 1) at either the ends or the sides, which required different orientations of the grasping hand. For example, when the bar was tilted 45° to the right (with respect to the sagittal plane of the participant’s body), grasping the ends required tilting the hand 45° to the right, whereas grasping the sides required tilting the hand 45° to the left. The visual stimulus was a rectangle that could appear in three different orientations, but the participants were told to ignore this feature and to focus on stimulus color. The fact that participants grasped the same object at either the ends or the sides allowed us to vary independently the congruency between the irrelevant stimulus orientation and the orientation of the to-be-grasped object (i.e., stimulus–object con-
In Experiment 1 we investigated whether and how the irrelevant orientation of a visual stimulus would affect the programming and execution of grasping movements directed toward a visible rectangular object that was tilted either 45° to the left or 45° to the right (see Figure 1). The visual stimulus was a congruently or incongruently oriented rectangle, or a cross combining both rectangles (the neutral condition). The color of the stimulus instructed the participants to grasp the object at the ends or at the sides, whereas stimulus orientation was irrelevant for the task. The neutral condition allowed us to evaluate whether grasping the ends and grasping the sides involved different motor demands.

In the present task, we varied stimulus–object congruency and stimulus–hand congruency independently of each other (see Figure 2). Our main question was whether the two types of congruency would affect the initiation or execution of the grasping movement. If stimulus–object congruency had an effect, we would learn that irrelevant information about stimulus orientation affects the processing of the to-be-grasped object. Similarly, if stimulus–hand congruency had an effect, we would learn that irrelevant information about stimulus orientation affects the programming of the required hand posture. If neither of the congruency types had an effect, we would learn that the grasping movement is only dependent on the relevant stimulus information (i.e., color) and on the spatial features of the to-be-grasped object.

1 Note that these two congruency relationships were confounded in the studies by Craighero et al. (1996, 1998).

2 Over the years, Craighero and colleagues have proposed two possible explanations for their findings: First, perception of stimulus orientation may affect the preparation of a congruent spatial movement, producing visual–motor priming (e.g., Craighero et al., 1996). Second, preparation of a spatial movement may prime the perception of a congruently oriented stimulus, producing motor–visual priming (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999). In our task, motor–visual priming was prevented because the participants could not prepare the grasping movement prior to the presentation of the visual stimulus; instead, they had to prepare the grasping movement in response to the visual stimulus. This task should be highly sensitive to visual–motor priming, whereas motor–visual priming should not occur.
Method

Participants. Sixteen volunteers (10 women, 6 men) with a mean age of 24 years (range = 19–31 years) participated for payment (5 euros, approximately $6.50) or for course credit. All participants in this and the following experiment classified themselves as being right-handed and as having normal (or corrected-to-normal) visual acuity. Moreover, all participants were naive with respect to the purpose of the study.

Apparatus and stimuli. The response apparatus (see Figure 1) consisted of a large wooden block (250 mm broad, 250 mm high, 80 mm thick) that was mounted on a wooden plate (400 mm broad, 500 mm long, 10 mm high). The to-be-grasped object consisted of a small wooden block (80 mm long, 30 mm broad, and 30 mm high) that was attached to the large block. The object could be rotated to four different orientations in steps of 45° (horizontal, left tilted, vertical, right tilted). Small metal plates (25 mm x 25 mm) were attached to the plate and to the object. One metal plate—the home key—was fixed to the plate in front of the large block. The distance between the home key and the to-be-grasped object was approximately 20 cm. Four metal plates were fixed to the object, one each on the left and right ends and on the upper and lower sides, respectively. The metal plates were touch sensitive and allowed us to measure participants’ RTs to the nearest millisecond.

Visual stimuli were shown on a 17-in. color monitor, with a screen-refresh rate of 60 Hz. There were three stimuli. Two stimuli were the outline shapes of a rectangle (21 mm x 53 mm). One rectangle was tilted 45° to the left; the other was tilted 45° to the right. The third stimulus was the outline shape of an X, which resulted from superimposing the two rectangles. The stimuli, either green or red, were presented on a black background.

Participants sat in front of a table with the monitor to their left and the response apparatus to their right. Unconstrained viewing distance to the screen was approximately 60 cm. The monitor and the response apparatus were connected to an IBM-compatible computer. A program written with the ERTS software (BeriSoft Corporation, Frankfurt, Germany) controlled stimulus presentation and response registration. The laboratory was lit in such a way that the stimuli and the response apparatus were clearly visible.

Procedure. The experiment was divided into six blocks of 60 trials. At the beginning of each block, the instructions were shown on the screen. Participants were told that they would have to grasp the bar at either the sides or the ends, depending on the color of an imperative stimulus. Half of the participants were instructed to grasp the object at the ends in response to green stimuli and at the sides in response to red stimuli. The other half of the participants received the opposite stimulus–response mapping. Moreover, participants were told that the imperative stimulus might appear in different orientations but that these orientations were irrelevant for the task and could be ignored. It is important to note that the orientation of the to-be-grasped object was constant within a given

Figure 2. Design of Experiment 1. The unfilled rectangles represent the imperative stimuli. The color of the stimulus lines instructed participants to grasp the object at either the ends or the sides. Different colors are indicated as dashed versus solid lines. The congruency between the (irrelevant) orientation of the visual stimulus and the orientation of the to-be-grasped object (stimulus–object congruency) and between the (irrelevant) orientation of the visual stimulus and the orientation of the grasping hand (stimulus–hand congruency) varied independently.
block of trials but varied between blocks. In half of the blocks, the object was tilted 45° to the left; in the other half of the blocks, the object was tilted 45° to the right, in both cases in relation to the sagittal plane of the participant’s body. Prior to each trial block, participants could practice a few trials, which were not analyzed. Each trial contained the following sequence of events. First, the message “Home Key” appeared at screen center until the participant placed the right index finger on the home key. When he or she did so, the screen went blank for 1,000 ms. Then, the imperative stimulus appeared at screen center for 500 ms. Depending on the color of the imperative stimulus, the participant’s hand had to leave the home key and grasp the object at the sides or at the ends as quickly as possible. The measurement of RTs and the registration of responses began with the onset of the imperative stimulus. The RT was defined as the time interval between the onset of the imperative stimulus and the point in time at which the index finger left the home key. The MT was defined as the time interval between the offset of the index finger from the home key and the point in time at which any metal plate at the object was touched.

Participants received error feedback in the following three cases. A corresponding error message was shown (a) when the sum of RT and MT was below 100 ms (anticipations), (b) when the sum of RT and MT was above 2,000 ms (delayed responses), or (c) when the object was touched at an incorrect plate (response errors). Each error message was shown for 1,000 ms at screen center. Trials containing at least one of these errors were repeated once at the end of the corresponding block. The experiment took about 1 hr.

Design. Experiment 1 rested on a 3 x 3 within-subjects design. The first factor was called stimulus–object congruency, and it concerned the relationship between the orientation of the imperative stimulus and the orientation of the to-be-grasped object, which could be congruent, incongruent, or neutral. The second factor was called stimulus–hand congruency, and it concerned the relationship between the orientation of the imperative stimulus and the orientation of the grasping hand (congruent, incongruent, or neutral). The orientation of the grasping hand was categorized in terms of an imaginary line between the thumb and the index finger, which corresponds to the main axis of the hand when grasping (see Mamassian, 1997).

A methodological problem arose from the fact that the different experimental conditions involved different motor demands. In particular, manipulations of stimulus–hand congruency and stimulus–object congruency involved different grip apertures: Grip aperture was large in conditions in which the stimulus–object relations and the stimulus–hand relations were both congruent or were both incongruent (cf. Figure 2). In contrast, grip aperture was small in conditions in which the stimulus–object relation was congruent and the stimulus–hand relation was incongruent or vice versa. These different motor demands could have affected the results of comparisons between overall RTs or overall MTs in the congruent versus incongruent conditions. To tackle this problem, we performed the data analysis in two steps. First, we compared performance with large versus small grip apertures in responses to neutral stimuli. When performance was found to be equivalent in the neutral conditions, we compared overall RTs and overall MTs in congruent versus incongruent conditions.

Results

RTs, MTs, and the percentages of response errors of Experiment 1 are displayed in Table 1. To eliminate outliers, we excluded RTs and MTs that were two standard deviations below or above the individual mean of each participant (averaged across conditions). RTs. Outlier trimming eliminated, on average, 0.8% of anticipatory responses and 2.8% of delayed responses. A first analysis revealed that RTs to neutral stimuli requiring a small grip aperture (369 ms) did not differ from RTs to neutral stimuli requiring a large grip aperture (368 ms), t(15) = 0.25, p = .80. Therefore, RTs were subjected to a 2 x 2 analysis of variance (ANOVA) with stimulus–hand congruency (congruent vs. incongruent) and stimulus–object congruency (congruent vs. incongruent) as within-subject factors. The ANOVA revealed no significant results: stimulus–hand congruency, F(1, 15) = 1.95, p = .18; stimulus–object congruency, F < 1; interaction, F < 1.

MTs. Outlier trimming eliminated, on average, 0.2% of anticipatory responses and 4.8% of delayed responses. The first analysis revealed that MTs to neutral stimuli requiring a small grip aperture (355 ms) did not differ from MTs to neutral stimuli requiring a large grip aperture (371 ms), t(15) = 1.52, p = .15. Therefore, MTs were subjected to a 2 x 2 ANOVA, with stimulus–hand congruency and stimulus–object congruency as within-subject factors. The ANOVA revealed a significant main effect of stimulus–hand congruency, F(1, 15) = 5.54, p < .05. Hand-congruent conditions produced faster movements (356 ms) than hand-incongruent conditions (362 ms). The main effect of stimulus–object congruency was not significant (F < 1); nor was the interaction, F(1, 15) = 2.22, p = .16.

Difference scores. We also analyzed the results of Experiment 1 by using difference scores instead of absolute RTs or MTs as the dependent measure. The difference scores were computed by subtracting absolute latencies in hand-congruent or object-congruent conditions and in hand-incongruent or object-incongruent condi-

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<th>Measure</th>
<th>Neutral (large ap.)</th>
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<th>Hand congruent O congruent</th>
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<td>RTs (ms)</td>
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<td>370</td>
<td>365</td>
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Note. H = hand; cong. = congruent; incongr. = incongruent; large ap. = large grip aperture (to the object’s ends); small ap. = small grip aperture (to the object’s sides); O = object; RTs = reaction times; MTs = movement times; PEs = percentages of errors.
tions from latencies in the corresponding neutral conditions. Analysis of difference scores revealed results similar to those for absolute latencies. In particular, the results for the main effects were identical for absolute latencies and difference scores. The two-way interaction was neither significant for RTs ($F < 1$) nor significant for MTs ($F < 1.2$).

**Discussion**

Experiment 1 showed that the irrelevant orientation of a visual stimulus affected the execution of visually guided grasping movements. Our results indicate that the processing of the stimulus information led to a direct activation of a spatially corresponding response. Moreover, and in contrast to previous studies (e.g., Craighero at al., 1996, 1998), the present task allowed us to separate the effects of irrelevant spatial information on object processing and on effector processing, respectively. In the movement times, we found an effect of stimulus–hand congruency but no effect of stimulus–object congruency. In particular, the irrelevant orientation of the stimulus allowed participants to perform movements more quickly when movements involved spatially corresponding hand orientations than when movements involved spatially noncorresponding hand orientations, regardless of how the to-be-grasped object was oriented. This result suggests that perceiving a tilted stimulus directly activates spatially corresponding hand movements. Moreover, the results also suggest that an imaginary line between the thumb and index finger is a useful index for evaluating hand orientation in grasping tasks.

**Experiment 2**

In Experiment 1, the congruency between stimulus orientation and hand orientation affected the execution of a grasping movement, whereas the congruency between stimulus orientation and the orientation of the to-be-grasped object failed to affect performance. However, the effect of stimulus–hand congruency in Experiment 1 was rather small, and it was present only in MTs and not in RTs. Therefore, we changed some aspects of the method in Experiment 2 to replicate and to extend our findings. First, we wanted to see whether the results of Experiment 1 could be replicated with a different set of orientations. The imperative stimulus, the to-be-grasped object, and the grasping hand were oriented horizontally or vertically in Experiment 2. Second, we made several changes to the stimuli to increase the size of congruency effects. In particular, the stimuli were matched in size to the to-be-grasped object. In addition, we increased the thickness of the stimulus outlines to intensify the saliency of stimulus information.

**Method**

**Participants.** Sixteen new volunteers (14 women, 2 men) with a mean age of 22 years (range = 18–36 years) participated for payment (5 euros, approximately $6.50) or for course credit.

**Apparatus and stimuli.** The apparatus was the same as that used in Experiment 1. The visual stimuli, however, were changed in four ways. First, the rectangles were oriented either horizontally or vertically on the screen. Second, the rectangles were made larger to match the size of the to-be-grasped object. Third, they were made more salient by increasing the thickness of their outlines. Fourth, the neutral stimulus was changed to a square (50 mm x 50 mm) that occupied an area similar to that of a rectangle. The neutral stimulus was changed because the cross used in Experiment 1 might have been more compatible with responses requiring a large grip aperture than with responses requiring a small grip aperture. In contrast, the neutral stimulus in Experiment 2 resembled an object that would require a grasping movement with an intermediate grip aperture, compared with the movements actually required.

**Procedure.** The procedure was the same as that of Experiment 1, except for the following change. The to-be-grasped object was oriented horizontally in 50% of the trial blocks, and it was oriented vertically in the remaining 50% of the blocks. Prior to each block, participants could practice a few trials, which were not analyzed.

**Design.** The design was the same as that of Experiment 1.

**Results**

The data from 2 participants could not be analyzed because of technical difficulties. In particular, the apparatus did not register their touches of the metal plates because the skin of their fingers was too dry. Hence, results are reported for the remaining 14

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**Note.** H = hand; cong. = congruent; incong. = incongruent; large ap. = large grip aperture (to the object’s ends); small ap. = small grip aperture (to the object’s sides); O = object; RTs = reaction times; MTs = movement times; PEs = percentages of errors.
participants. RTs, MTs, and percentages of response errors from Experiment 2 are displayed in Table 2.

RTs. Outlier trimming eliminated, on average, 0.1% of anticipatory responses and 1.2% of delayed responses. A first analysis revealed that RTs to neutral stimuli requiring a small grip aperture (361 ms) did not differ from RTs to neutral stimuli requiring a large grip aperture (362 ms), *t*(13) = 0.05, *p* = .96. Therefore, RTs were subjected to a 2 × 2 ANOVA with stimulus–hand congruency (congruent vs. incongruent) and stimulus–object congruency (congruent vs. incongruent) as within-subject factors. The ANOVA revealed a significant main effect of stimulus–hand congruency, *F*(1, 13) = 8.53, *p* < .05. Hand-congruent conditions produced faster responses (357 ms) than hand-incongruent conditions (366 ms). The main effects of stimulus–object congruency, *F*(1, 13) = 1.71, *p* = .21, and the interaction (*F* < 1) were not significant.

MTs. Outlier trimming eliminated, on average, 0.4% of anticipatory responses and 4.6% of delayed responses. The first analysis revealed that MTs to neutral stimuli requiring a small grip aperture (370 ms) did not differ from MTs to neutral stimuli requiring a large grip aperture (377 ms), *t*(13) = 0.50, *p* = .63. Therefore, MTs were subjected to a 2 × 2 ANOVA with stimulus–hand congruency and stimulus–object congruency as within-subject factors. The ANOVA revealed a significant main effect of stimulus–hand congruency, *F*(1, 13) = 23.55, *p* < .001. Hand-congruent conditions produced faster movements (370 ms) than hand-incongruent conditions (388 ms). The main effects of stimulus–object congruency and the interaction were not significant (both *Fs* < 1).

Difference scores. We also analyzed the results of Experiment 2 using difference scores instead of absolute RTs or MTs as the dependent measure. Both sets of analyses produced consistent results. In particular, the results for the main effects were identical for absolute latencies and difference scores. The two-way interaction was neither significant for RTs nor significant for MTs (both *Fs* < 1).

Percentages of response errors. A first analysis revealed that the error percentages in neutral conditions with a small grip aperture (18.5%) were somewhat higher than those in neutral conditions with a large grip aperture (9.0%), *t*(13) = 2.10, *p* = .06. Because this difference was not significant, error percentages were subjected to a 2 × 2 ANOVA with stimulus–hand congruency and stimulus–object congruency as within-subject factors. The main effects were not significant for stimulus–hand congruency, *F*(1, 13) = 2.27, *p* = .16; and for stimulus–object congruency (*F* < 1), and the interaction also failed to reach significance, *F*(1, 13) = 4.41, *p* = .06. If anything, the marginally significant interaction indicates a larger effect of hand congruency when the stimulus–object relationship was also congruent (*D* = 11.2%) than when the latter relationship was incongruent (*D* = 7.7%).

Discussion

Experiment 2 replicated and extended the results of Experiment 1. First, Experiment 2 replicated the effects of stimulus–hand congruency with a different set of stimulus, object, and hand orientations (i.e., horizontal vs. vertical). Again, the irrelevant orientation of the stimulus allowed participants to produce movements involving spatially corresponding hand orientations more quickly than movements involving spatially noncorresponding hand orientations, regardless of how the to-be-grasped object was oriented. In contrast to Experiment 1, however, this stimulus–hand congruency effect was present not only in MTs but also in RTs. The observation of congruency effects in RTs strongly suggests that perceiving a visual stimulus modulates the programming (i.e., selection) and initiation of congruently oriented hand movements. By contrast, the observation of congruency effects in MTs may reflect effects on the level of programming (i.e., selecting movement parameters) or on the level of controlling a movement.

Second, the effects of stimulus–hand congruency were larger in Experiment 2 than in Experiment 1. This was probably due to our manipulations of the stimuli. In particular, the increased stimulus size and the increased thickness of the stimulus lines may have intensified the irrelevant information about stimulus orientation in Experiment 2.

Third, Experiment 2 replicated the absence of stimulus–object congruency effects. Neither of the dependent variables revealed an impact of the congruency between the irrelevant stimulus orientation and the orientation of the to-be-grasped object. Hence, when the orientation of the to-be-grasped object remained constant within blocks of trials, as in the present task, stimulus–object congruency did not affect performance.

General Discussion

In this study we investigated whether the irrelevant orientation of a visual stimulus would affect the programming or the execution of a grasping movement toward a visible object. In two experiments, the color of a visual stimulus instructed participants to grasp a rectangular bar at either the ends or the sides, which required different orientations of the grasping hand. This task allowed us to independently vary the congruency between the irrelevant orientation of the visual stimulus and the orientation of the hand (i.e., stimulus–hand congruency) and the congruency between the irrelevant orientation of the visual stimulus and the orientation of the to-be-grasped object (i.e., stimulus–object congruency). The main dependent variables were the time between stimulus onset and movement onset (RT) and the time between movement onset and offset (MT). There were three interesting results. First, perceiving the irrelevant orientation of a visual stimulus affected the preparation and execution of a grasping movement toward a visible object. Second, stimulus–hand congruency systematically affected the grasping movements, whereas stimulus–object congruency had no effects. In particular, congruency between stimulus and hand orientation allowed for better performance than did incongruency. These effects were observed for two different sets of orientations: in Experiment 1, tilted 45° to the left versus 45° to the right; in Experiment 2, horizontal versus vertical. Third, the effects of stimulus–hand congruency were observed in both RTs and MTs, at least in Experiment 2. We also analyzed the percentages of response errors, but we observed no significant results.

The present results demonstrated an S–R correspondence effect for spatial orientation in visually guided grasping movements. This correspondence effect for orientation resembles the well-known S–R correspondence effects for spatial location, such as the Simon effect. In both cases, correspondence between an irrelevant spatial stimulus feature (location or orientation) and a relevant response
feature affects the preparation and execution of the response. As already noted, the Simon effect has typically been explained on the basis of a distinction between direct and indirect routes from perception to action (e.g., Kornblum et al., 1990), without any reference to the neuroanatomical substrate of these routes. Interestingly enough, research in the areas of neuropsychology and neuropsychology has also led to the distinction between direct and indirect routes from perception to action (e.g., Riddoch et al., 1989; Rumiati & Humphreys, 1998).

We believe that the results of these experiments should also be interpreted in terms of two parallel processing routes from perception to action. In particular, we suggest that in our task, two parallel but functionally independent processing pathways translated different properties of the visual stimulus into motor commands. The first pathway translated the task-relevant stimulus information (i.e., color) into a movement that was directed toward either the sides or the ends of the object, according to task instructions. Because this S–R translation had to access semantic knowledge and was probably mediated by verbal processes, it constitutes an indirect route from perception to action, which may be associated with theventral stream of visual processing. The second pathway translated the task-irrelevant stimulus information (i.e., orientation) into spatially congruent movement parameters. In our task, the irrelevant stimulus orientation affected the programming of hand rotation but not so much the processing of the spatial features of the to-be-grasped object. We suggest that the direct activation of hand orientation by the irrelevant stimulus orientation occurred via the dorsal pathway of visual processing. The fact that stimulus–hand congruency effects were found for both RTs and MTs in the present study suggests that irrelevant stimulus orientation affected the preparation, and possibly also the execution, of grasping movements.

By demonstrating effects of irrelevant stimulus orientation on visually guided grasping movements, the present results add to existing knowledge on the functional properties of such movements. Cant et al. (2005) suggested that memory-guided, but not visually guided, grasping movements are susceptible to priming. In their experiments, participants perceived or grasped an object about 2 s before the onset of the go signal. This information affected the subsequent initiation of a grasping movement toward the same object when the to-be-grasped object could not be seen during movement execution (memory-guided grasping movement) but not when the object was visible (visually guided grasping movement). This observation supports the real-time view of motor programming in the dorsal pathway (Goodale et al., 2004). We complement these findings in showing that the perception of task-irrelevant spatial features of objects (or object-like stimuli) affects simultaneous preparation and execution of visually guided grasping movements.

In the present experiments, we observed an S–R correspondence effect for spatial orientation even though the orientation of the visual stimulus was completely irrelevant for the task of grasping a visible object. The fact that stimulus orientation was irrelevant, however, does not mean that processing of this feature ran automatically in our task. Usually, the notion of automaticity implies that processing runs independently of attention and intention (e.g., Posner & Snyder, 1975). We do not believe that these two preconditions were met in the present task. With regard to attention, previous research has shown that object-based attention selects both relevant features (e.g., color in the present experiments) and irrelevant features (e.g., orientation in the present experiments) of an attended object for further processing (O’Craven, Downing, & Kanwisher, 1999; Wühr & Waszak, 2003). With regard to intention, it appears very likely that effects of stimulus orientation are confined to situations in which spatially oriented movements are required and in which participants are set to process the orientation of visual objects for guiding their movements. In other words, we believe that in our task, the ability of the stimulus to activate motor parameters was due to the fact that the stimulus was very similar to the to-be-grasped object. The increase of the congruency effects from Experiment 1 to Experiment 2, when the similarity between the stimulus and the to-be-grasped object was increased, supports this interpretation.

A further result of the present experiments was that stimulus–object congruency did not affect behavior. This implies that the preactivation of the orientation of the to-be-grasped object did not modulate response programming or execution in the present task. One reason for this may have been that the orientation of the object was varied between but not within blocks of trials. In effect, participants were able to specify object orientation in advance for a whole block of trials, and this may have weakened possible effects of stimulus–object congruency (see Morein-Zamir, Henik, & Spitzer-Davidson, 2002, for a similar conclusion). Another reason may have been that participants represented the two possible responses to each visual stimulus exclusively in terms of response features. For example, when the object was oriented vertically in Experiment 2, participants could have represented the responses in terms ofhand orientation (horizontal or vertical) and grip aperture (large or small). In this case, the response set consisted of the vertically oriented hand with a large grip aperture and the horizontally oriented hand with a small grip aperture. Note that these response representations referred only implicitly to the orientation of the to-be-grasped object.

These considerations may explain why stimulus orientation preactivated the representation of a congruently oriented hand but not the representation of a congruently oriented object. In particular, it is possible that the cognitive representation of the grasping movement, which is susceptible to S–R correspondence effects, may only entail those features of an action that are needed to select between possible responses or to control execution of a selected action (e.g., Ansorge & Wühr, 2004). In the present study, an explicit representation of object orientation was necessary neither for response selection nor for movement control. Future research may test these hypotheses by using an experimental setup that allows investigators to vary stimulus orientation, hand orientation, and object orientation from trial to trial.

In summary, two experiments showed that the irrelevant orientation of a visual stimulus can preactivate the representation of a congruently oriented hand in visually guided grasping movements. This suggests that spatial object features, such as stimulus location and stimulus orientation, have direct (or privileged) access to the motor system, possibly via the dorsal stream of visual processing. In contrast, nonspatial object features, such as stimulus color, have to be translated into motor parameters via an indirect processing pathway, which may be associated with theventral stream of visual processing.
References


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