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Context Effects on the Processing of Action-Relevant Object Features

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In 4 experiments, we investigated the effects of object affordance in reach-to-grasp actions. Participants indicated whether a depicted small or large object was natural or manmade by means of different object-grasping responses (i.e., with a power or a precision grip). We observed that the size of the depicted object affected the grasping kinematics (grip aperture) and the reach-onset times of compatible and incompatible actions. Additional experiments showed that the effect of perceived object size on motor response was modulated by contextual action information and the observation of others' actions with the object. Thus, beyond the observation of object affordance effects in natural grasping actions, this study suggests that the coupling between object perception and action is not static and obligatory. Behavioral effects of action-relevant object features seem rather to depend on contextual action information.

Keywords: object affordance, action context, object grasping, action observation, action intention

Over the past decade, cognitive science has shown increased interest in understanding the relation between the functional processes necessary to initiate a goal-directed action and the processes essential for perception and thought. For example, compatibility effects between object perception and motor response have been shown to be bidirectional. That is, stimulus features can affect the characteristics of potential actions (i.e., stimulus–response compatibility; e.g., Hommel, 1995; Kornblum, Hasbroucq, & Osman, 1990; Simon, 1969), and characteristics of a prepared or executed action can influence the perception of stimulus features (i.e., response–stimulus compatibility; e.g., Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Fagioli, Ferlazzo, & Hommel, 2007; Fagioli, Hommel, & Schubotz, 2007; Müsseler & Hommel, 1997). Two dominant theoretical views of the coupling between object perception and action can be distinguished: theories of direct perception and theories of ideomotor action.

Theories of direct perception assume that perceptual processes are intimately related to motor processes and claim that people perceive each object in their environment in terms of potentially afforded behaviors (e.g., Gibson, 1979). Gibson (1979) argued that the affordances of objects are based on their intrinsic perceptual properties, registered automatically and without the need for further cognitive processes such as object recognition. To test this notion, Tucker and Ellis (2001) required their participants to indicate the semantic category of natural and manmade objects by mimicking either a full or a precision handgrip. They found a compatibility effect between the size (large or small) of the presented object and the required response (full or precision handgrip). They interpreted their findings as an object affordance effect reflecting the directly perceived relation between certain visual object properties and possible motor responses (see also Derbyshire, Ellis, & Tucker, 2006; Ellis & Tucker, 2000; Ellis, Tucker, Symes, & Vainio, 2007; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008).

Interestingly, Glover, Rosenbaum, Graham, and Dixon (2004) demonstrated that interference effects between object properties and motor responses are not only present for simple button-press responses but can also be found in natural object–directed reach-to-grasp movements. To be precise, they investigated the influence of object words on the movement kinematics of grasping actions and observed larger maximum grip apertures after reading words representing relatively large objects (e.g., *APPLE*) than after reading words representing relatively small objects (e.g., *GRAPE*). As a more detailed analysis revealed, the object affordance effects in word reading on grasping kinematics were already present very early in the reach, suggesting that the effect of the object words emerged during action planning and online motor control (see also Glover, 2004). Taking into account the finding of automatic word-reading effects, it seems plausible to assume that the processing of visual object features (e.g., object size) also affects the kinematics of natural reach-to-grasp actions. However, until now there has been no behavioral evidence for such an impact of visual action-related object information on grasping kinematics that went beyond response latency measurements and a facilitated execution of compatible motor response.

The finding of object affordance effects on button-press latencies has been interpreted as support for the idea that perceived object affordances automatically and obligatorily affect the planning of subsequent motor responses. However, the notion that the processing of visual object information takes place in an automatic fashion does not imply that simply viewing graspable objects automatically potentiates components of the actions they afford.

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Empirical evidence for this is coming, for instance, from a study of Tipper, Paul, and Hayes (2006), which recently demonstrated that action affordance effects on grasping were larger when participants were presented with an active action state of the object, such as a door handle depressed by 45%, than when they were presented with the same object in a passive state (i.e., horizontal). According to Tipper et al., this benefit of the active state suggests that the activation of affordance from object perception is context dependent and might be mediated by mental simulations of another person's action with the object. Moreover, Bub and Masson (2006) have recently demonstrated that object affordance effects emerge only if the observer attends to the object. Passive viewing without the intention to act does not evoke hand gesture knowledge. Taken together, recent observations have argued against the idea that processing of action-related object features obligatorily activates consistent action plans. That is, even though action-relevant information is probably automatically extracted and processed and object perception is not, this knowledge does not obligatorily affect processes of action planning and execution. Rather, the behavioral impact of perceived object affordance seems to depend heavily on the action context in which the object is presented as well as on the concurrent motor intentions of the observer.

Another approach to the coupling of perception and action is provided by theories of ideomotor action, which basically hold that movements are exhaustively coded in terms of their sensory consequences (e.g., Greenwald, 1970), and by theories of common coding, which assume that representations of perception and action are based on the same cognitive codes and thus operate on the same representational domain (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990). The central assumption shared by both views is that motor actions and perceptual effects are highly interrelated and mutually dependent. Experimental evidence for this idea comes from studies on imitation showing that the perception of a hand or finger movement facilitates the execution of consistent motor actions (Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Stürmer, Aschersleben, & Prinz, 2000). For example, Stürmer et al. (2000) required participants to open or close their hand in response to the color of a picture of an opening or closing hand. Although the depicted action was irrelevant to the assigned task, participants responded faster when they had to execute the same action as that in the picture. Likewise, Brass et al. (2001) demonstrated that people are faster in initiating a finger movement to an arbitrary cue when an irrelevant but response-compatible visual finger movement is shown simultaneously. Together, the reports of automatic imitation effects show that perceived sensory action consequences automatically activate the representations of associated actions.

In contrast to the direct perception view, the common coding approach predicts perceptual effects on action planning and assumes a bidirectional connection between perception and action—a notion that also implies the possibility of action-induced effects on perception (Hommel et al., 2001). Because visual objects and motor actions are assumed to be represented by shared features codes, it is expected that action planning affects perceptual processing by biasing the cognitive system toward feature dimensions that are relevant for the preparation of the intended response (Hommel et al., 2001). For instance, the intention to grasp an object should prepare the visual system for the processing of grasp-related object features. Such enhanced activation of codes of features defined on motor-relevant dimensions can be understood as a sort of intentional weighting process (see, e.g., Hommel, in press). In fact, several studies have reported evidence for action-induced effects and demonstrated that the preparation of a motor response affects visual processing of objects and events that is consistent with the currently intended action (Craighero et al., 1999; Fagioli, Hommel, & Schubotz, 2007; Hamilton, Wolpert, & Frith, 2004; Lindemann & Bekkering, 2009; Schubö, Prinz, & Aschersleben, 2004; Wohlschläger, 2000; Zwickel, Grosjean, & Prinz, 2007). As one example, Craighero et al. (1999) demonstrated that the processing of a visual stimulus is facilitated if it affords the same type of grasping response as the participant concurrently intends to perform. In their paradigm, participants were instructed to prepare to grasp differently oriented wooden bars but to delay the response execution until a visual go-signal was presented. They observed faster detections of go-signals that afforded the same type of grip as that involved in the prepared action, indicating that the preparation of an object-directed motor response facilitates the visual processing of action-consistent stimuli and showing that the intention to grasp an object is sufficient to constitute an action context that modulates visual perceptual processing.

Interestingly, as we know from recent research on the representation of functional object knowledge, the mere observation of a grasping action or hand posture strongly influences semantic judgments of graspable objects (Paulus, Lindemann, & Bekkering, in press; Vainio et al., 2008; Yoon & Humphreys, 2005). Yoon and Humphreys (2005), for instance, presented pictures of tools together with hands that were holding the objects in different ways and showed that this contextual action information strongly influenced the time taken to identify how the object is typically used. Taking into account the view of the bidirectional perception–action coupling and the finding that task-irrelevant action information modulates the semantic processing of familiar objects, it might be speculated that action-induced effects on the perceptual processing of objects and their affordances might be influenced by contextual action information associated with the grasp and type of use. However, so far we do not know much about the role of others' actions on the representation of affordances and a possible interplay between processes of action observation and object perception.

The major aim of this research was therefore to study object affordance effects in natural reach-to-grasp actions while focusing on the role of the action context in the processing of object affordances. In four experiments, we required participants to judge the semantic category (i.e., natural or manmade) of presented objects. In contrast to previous studies on stimulus–response compatibility effects in object perception (e.g., Tucker & Ellis, 2001), we required participants to indicate their decisions by performing different types of reach-to-grasp movements. The aim of the first experiment was to determine whether the perception of visual object properties interferes with the planning and execution of natural grasping movements by investigating the effects of object affordances on the reach onset times and movement kinematics of grasping actions. In subsequent experiments, we applied this paradigm to examine effects of action context on object perception. In particular, we focused on the role of the perception of another's action by examining the potential influence of action observation on the presence of the object affordance effect, that is, the compatibility effect between presented object and executed grasping response.

Experiment 1

In Experiment 1, we examined the presence of object affordance effects in natural grasping actions and moreover tested whether the processing of action-related object features has an impact on both components of a reach-to-grasp action, that is, on the reaching (movement initiation times) and on the grasping (maximum grip aperture [MGA]). To this end, we required participants to judge the semantic category (natural or manmade) of a visually presented object (fruit or tool) and to reach out for an object (manipulandum) placed in front of them. More important, the decisions had to be indicated by grasping the manipulandum with either a power grip or a precision grip. We expected the time to initiate reaching to be shorter when it was cued by an object affording the same type of grip rather than a different type of grip, that is, an object affordance effect (Tucker & Ellis, 2001). Taking into account previous research showing an impact of semantic magnitude information on grasping kinematics (Glover et al., 2004; Lindemann, Abolafia, Girardi, & Bekkering, 2007; Lindemann, Stenneken, van Schie, & Bekkering, 2006), we also expected the perceived object size to affect the aperture of the hand during the reaching phase, as revealed by an enlarged MGA for pictures of large as compared with small objects.

Method

Participants. Twenty-one students of Radboud University Nijmegen took part in the experiment in return for €4.50 ($6.39) or course credit. All were right handed, had normal or corrected-to-normal vision, and were naive with respect to the purpose of the study.

Setup. In a dimly lit room, participants sat in front of a table and were required to reach out for a wooden object (i.e., manipulandum). The manipulandum consisted of two parts: a large cylinder (diameter = 6 cm, height = 7 cm) at the bottom and a small cylinder (diameter = 0.7 cm, height = 1.5 cm) attached to top of the large cylinder. It could be grasped in one of two ways: either with a power grip at the large cylinder or with a precision grip at the small cylinder (see Figure 1B). The manipulandum was placed on the right side of the table behind an opaque screen (height = 44 cm, width = 45 cm), allowing participants to reach it comfortably with their right hand without visual control (see Figure 1A). At a distance of 30 cm from the center of the object, we fixated a small pin (height = 0.5 cm, diameter = 0.5 cm) that served as a marker for the starting position of the reach-to-grasp movements.

Stimuli. All stimuli were displayed on a gray background using a 17-in. (43.2-cm) monitor (refresh rate = 100 Hz). Each target stimulus consisted of a color photograph of a small or large manipulable object. At a viewing distance of 50 cm, horizontal and vertical visual angle ranged from about 3° (small objects such as a paperclip) to 30° (a large object such as a saw). We used 20 manmade objects and 20 natural objects (see Appendix A for a list of all objects). Half of the objects were small and consequently afforded a precision grip action (e.g., a sharpener or a grape), and the other half were large and required a power grip action (e.g., a hammer or a banana).[1] Each object was depicted in two different horizontal orientations. One orientation required a right-hand grasp (e.g., handle on the right side), and the other required a left-hand grasp (e.g., handle on the left side). Pictures of objects with opposite alignments were obtained by mirroring the photographs.

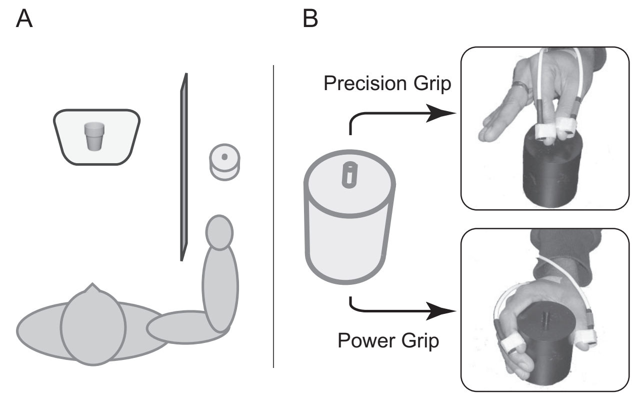

Figure 1. Basic experimental setup. A: Participants sat at a table with a computer screen and a manipulandum. An opaque screen blocked the view of the manipulandum and the right hand. B: The manipulandum consisted of two segments: a large cylinder at the bottom, affording a power grip, and a small cylinder at the top, affording a precision grip.

Procedure. Before the experiment started, participants performed a short preexperimental block in which they were required to grasp the manipulandum with either a precision or a power grip, depending on which colored dot was presented on the screen. Specifically, they were required to reach out for the manipulandum and to grasp it either at its large bottom part, using all of the fingers on one hand (i.e., power grip response), or at its small top part, using only their thumb and index finger (i.e., precision grip response). The actual experiment started only when participants were able to perform the grasping movements correctly and fluently without vision.

At the beginning of each experimental trial, a gray fixation cross was presented at the center of the screen; it indicated that participants should place their index finger in the starting position. As soon as their hand was placed correctly, the fixation cross turned black and disappeared 1,500 ms later. After a random interval of 500–2,000 ms, the target stimulus (i.e., tool or fruit) was presented. The participants' task was to judge the semantic category of the depicted object and to indicate their decision by performing one of the two practiced actions (i.e., precision or power grip). Responses had to be made as quickly and accurately as possible. The target stimulus remained visible until the onset of reaching or until 3,000 ms had elapsed. After performing the reach-to-grasp movement, participants were required to grasp the object until the gray fixation cross appeared to indicate the start of the next trial. A stop sign, together with a beep sound (4400 Hz, lasting 200 ms),

[1] Large and small objects were chosen considering the kind of grip required to pick them up. We presented 56 pictures of manmade and natural objects to 18 participants and asked them to indicate whether the object required a precision or power grip to handle it appropriately. The 40 objects selected for the study were classified to a rate of 100% of the responses as either a precision or a power grip object.

was presented as error feedback if reach-to-grasp movements were initiated before onset of the target stimulus.

Design. The mapping between the semantic object category and the required response was counterbalanced between participants; that is, half of the participants performed a power grip action in response to natural objects and a precision grip action in response to manmade objects. For the other half, the stimulus–response mapping was reversed. The experimental block consisted of 160 trials (20 objects × 2 semantic categories × 2 object orientations × 2 repetitions). All trials were presented in a randomized order. In addition, at the beginning of the experiment we presented 20 practice trials consisting of four sample objects[2] that were not used in the experimental trials. The experiment lasted about 45 min.

Data acquisition. To record the hand movements, we used an electromagnetic position tracking system (miniBIRD 800TM, Ascension Technology Corporation, Burlington, VT). Three sensors were attached to the participants' thumb, index finger, and right wrist. Sensor positions were tracked at a sampling rate of 103 Hz. The movement kinematics were analyzed offline. A fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz was applied to the raw data. The onset of a reach-to-grasp movement was defined as the first moment in time at which the tangential velocity of the index finger sensor exceeded the threshold of 10 cm/s. For the offset, we used the opposite criterion, taking the time of the first sample in which the velocity decreased below this threshold.

As dependent variables for the statistical tests, we calculated the mean response latencies of the reaching movements (response time [RT], defined as the mean time elapsed between onset of picture presentation and onset of reach-to-grasp movement), and the MGA (defined as the maximum distance between the thumb and the index finger during reaching) of the grasping. Anticipation responses (response before onset of go-picture presentation and RTs < 100 ms), missing responses (no reactions and RTs > 1,000 ms), and incorrectly performed actions (e.g., incorrect grasping, wrong type of grip, movement stopped while reaching) were considered to be errors and excluded from further analyses. A Type I error rate alpha of .05 was used in all statistical tests reported here.

Results

The rate of anticipations (<1%) and errors (1.8%) was low, showing that participants had carefully executed the object categorization task.

Reach onset latencies. We subjected the mean RTs to a repeated measures analysis of variance (ANOVA) with object size (large or small) and motor response (power grip or precision grip) as within-subjects factors. The analysis revealed a significant main effect of object size, $F(1, 20) = 39.53$, $p < .001$, indicating that large objects were identified faster (469 ms) than small objects (493 ms). There was a tendency for power grip responses to be initiated faster (477 ms) than precision responses (485 ms), $F(1, 20) = 3.37$, $p = .08$. The two-way interaction between object size and motor response was significant, $F(1, 20) = 6.76$, $p < .02$ (see Figure 2). As revealed by post hoc *t*-test comparisons, when large objects were presented, participants initiated power grip responses

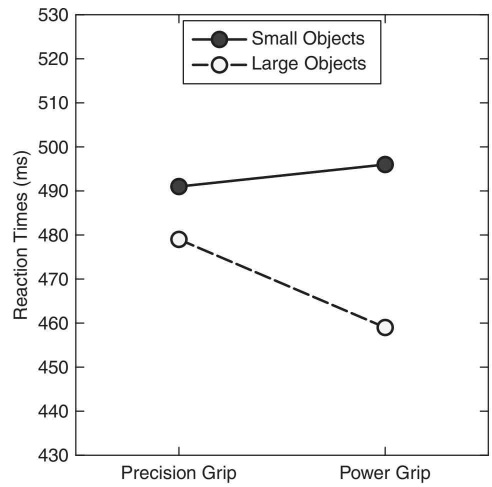

Figure 2. Mean response latencies of the grasping movements in Experiment 1 as a function of the factors motor response and object size.

(459 ms) faster than precision grip responses (479 ms), $t(1, 19) = 2.84$, $p < .001$; when small objects were presented, RTs for the precision grip responses (491 ms) were descriptively shorter than for the power grip responses (496 ms). However, this contrast failed to reach significance ($t < 1$).

Grasping kinematics. We conducted a repeated measures ANOVA with the factors object size (large or small) and object category (natural or manmade) on the mean MGAs. The analysis showed a main effect of object size, $F(1, 20) = 4.58$, $p < .05$. That is, grip apertures were larger when grasping the manipulandum while viewing large objects (109.7 mm) than while viewing small objects (108.5 mm). Neither the main effect of object category nor the interaction between the two factors reached significance (both Fs < 1).

Discussion

Experiment 1 demonstrates that reach-to-grasp movements are affected by visual processing of objects affording different types of actions. The object compatibility effect on the reach onset latencies reflects that participants initiated power grip actions faster in response to large objects (e.g., a hammer) than in response to small objects (e.g., a sharpener). This finding provides the first direct empirical support for the notion of object affordance effects in complex natural grasping actions and thus extends previous findings of object affordance effects on the execution of finger movements that are involved in power or precision grip actions (Tucker & Ellis, 2001). Moreover, we observed that the MGA was larger while viewing a large object than while viewing a small object. The object size effect in the grasping kinematics demonstrates an impact of task-irrelevant magnitude information on motor behavior, as has previously been reported for word-reading and number-processing tasks (Glover et al., 2004; Lindemann et al., 2007), and shows that similar effects also emerge during processing of visual

[2] A cherry tomato, a tangerine, a carving fork, and a nail were used as sample objects for the training trials.

information. The object affordance effect in the reach-onset latencies was significant only for large objects. This dissociation between small and large objects was possibly driven by the fact that small objects were more difficult for the participants to discriminate, and as a result, they were not strongly associated with a particular motor representation. The idea of object affordances and the observation of response compatibility effects in object perception has led many researchers to conclude that the processing and representation of action-relevant visual information in object perception takes place in a rather automatic way (see, e.g., Tucker & Ellis, 2001). The finding of interference effects between object perception and motor actions, however, does not inevitably imply that the detection of action-relevant object features automatically activates motor representations suited for manipulation of objects (Phillips & Ward, 2002). Alternatively, it might be possible that affordances are automatically processed but do not obligatorily activate motor actions.

As mentioned in the introduction, ample evidence has shown that the intention to perform a motor movement facilitates the processing of action-related perceptual features such as object size (Fagioli, Hommel, & Schubotz, 2007) or orientation (Craighero et al., 1999) or the detection of action-consistent events (Lindemann & Bekkering, 2009). It has therefore been argued that the activation of action representations has a direct impact on subsequent attentional and perceptual processes by facilitating the processing of action-relevant features and dimensions. Along the lines of this intentional weighting hypothesis (see Hommel, in press), one might also speculate that the mere observation of another person's object grasping modulates the processing of action-relevant object features. If so, one might expect that object affordance effects depend on concurrently activated representations of others' motor behavior and contextual information about others' action intentions. A possible means of testing this hypothesis is to manipulate the action context, that is, the scenario in which the object is perceived, and to investigate whether the presence of another person's grasping action affects the perceptual processing of action-related object features and, thus, the activation of afforded actions. We therefore conducted another experiment, the aim of which was to examine the influence of contextual information on the presence of object affordance effects.

Experiment 2

In Experiment 2, we investigated whether the action context in which an object is perceived affects the presence of object affordance effects on grasping responses. As in Experiment 1, participants were instructed to reach out and grasp the manipulandum differently depending on the semantic decision task regarding the nature of visually presented large and small objects. To investigate the influence of observing another's action on processing of object affordances, we presented the objects in the context of different grasping actions by also showing pictures of hands approaching the object with either a power or a precision grip. Because the depicted objects were either small or large, the grip size of presented hand postures was thus either appropriate or inappropriate with respect to the action afforded by the object. Because of the manipulation of observed hand–object relations, it was possible to test whether object affordance effects are modulated by action context.

As we know from previous research on ideomotor compatibility effects (Brass et al., 2000, 2001; Stürmer et al., 2000), the observation of hand postures or hand movements has a direct impact on the motor system and facilitates the execution of congruent motor actions. If object affordances also automatically potentiate components of actions, the object compatibility effect on grasping actions should not be mediated by contextual information. In this case, we expect to find two independent but not interfering effects, that is, an effect of the object's affordance and an ideomotor effect of the hand posture. If the processing of object affordances, however, is modulated by the action context, we expect that the effects of object affordance on motor responses will be modulated by the depicted hand posture and its relation to the required response.

Method

Participants. Twenty-four students of Radboud University Nijmegen took part in the experiment. All were right handed, had normal or corrected-to-normal vision, and were naive with respect to the purpose of the study. They received €4.50 ($6.39) or course credit for their participation.

Setup stimuli and data acquisition. The experimental setup and the data acquisition were identical to those of Experiment 1. A new set of color photographs of 20 small or large tools (i.e., manmade objects) and 20 small or large fruits (i.e., natural objects) were used as target stimuli (see Appendix B for a list of all objects). In contrast to previous studies, each object was always presented along with a photograph of the left or right hand (see Figure 3A). Each object subtended a visual angle of between 3° (small objects such as a paperclip) and 25° (large objects such as a teapot). The pictures of the hands (visual angle = 18°) were presented randomly to the left or the right of the object. More important, all stimuli were assembled in such a way that the depicted hand appeared to approach the object. That is, right hands were always shown to the left of the object and left hands to the right. The left-hand picture was obtained by mirroring the photograph of the right hand. For the no-go trials, the picture of the hand was tinted blue.

Procedure. The procedure was basically identical to that of Experiment 1. Participants indicated the semantic category of the presented object (i.e., manmade or natural) by means of different grasping responses (i.e., precision or power grip). To ensure that participants paid attention to both object and hand, we introduced additional no-go trials in which the hand was tinted blue. In these trials, participants had to refrain from responding irrespective of the object category.

Design. The mapping between the semantic object category and the required response was again counterbalanced between participants. The experimental block consisted of 160 randomized experimental trials (20 objects $\times$ 2 semantic categories $\times$ 2 grasping postures $\times$ 2 object orientations) and 32 no-go trials. Again, motor responses were trained in a short preexperimental block. The experiment lasted about 45 min.

Because of the factorial combinations of the required grasping responses and the two orthogonal stimulus features of object size and depicted hand posture, each trial was compatible or incompatible with respect to object size and posture. That is, depending

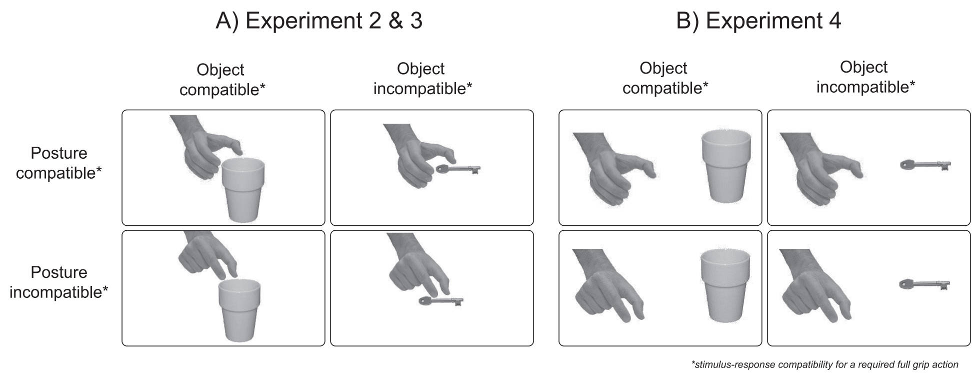

Figure 3. Examples of stimuli in Experiments 2, 3 (A), and 4 (B) for the two types of stimulus–response compatibility—object and hand posture—in the case of a required power grip action. The side of hand presentation (left or right) was counterbalanced. Note that because pointing actions were unrelated to hands and objects, responses in Experiment 3 could not be classified as object or posture compatible (see text for details).

on whether the grip was the same or different from that of the hand in the photograph, a response could be considered as posture compatible or incompatible. Moreover, each response was, depending on whether the grip size matched the object size, either object compatible or incompatible, as was the case in Experiment 1.

Results

The low percentage of anticipations (<1%) and incorrectly performed actions (3.0%) indicated that participants had performed the task carefully.

We subjected the mean RTs to an ANOVA with the within-subjects factors motor response (power grip or precision grip), object compatibility (compatible or incompatible), and posture compatibility (compatible or incompatible). The analysis revealed a effect for the factor motor response, $F(1, 23) = 6.98$, $p < .01$, showing that power grip responses (572 ms) were initiated faster than precision grip responses (596 ms). Also, the main effect of object compatibility reached significance, $F(1, 23) = 9.39$, $p < .01$, indicating that grasping actions compatible with the action afforded by the object (578 ms) were initiated faster than incompatible grasping actions (589 ms). There was no effect for the factor posture compatibility, $F(1, 23) = 1.6$. More important, however, there was a significant interaction between the factors object compatibility and posture compatibility, $F(1, 23) = 13.6$, $p < .001$ (see Figure 4). No other interaction of the ANOVA reached significance (all Fs < 1).

As post hoc t-test comparisons revealed, responses were faster toward compatible objects only if the depicted posture was compatible with the required response (572 ms vs. 593 ms), $t(23) = 4.32$, $p < .001$. For posture-incompatible trials, however, there was no effect of object compatibility (585 ms vs. 586 ms; $|t| < 1$).

Discussion

Experiment 2's results show that object affordance effects were present only if the depicted hand posture was compatible with the required grasping action. That is, the execution of grasping was facilitated only if both stimulus features (i.e., object size and hand posture) were compatible with the response. However, in conditions in which one or both stimulus features were incompatible, RTs did not differ from one another. This finding clearly excludes the possibility of two independent effects of object size and hand posture; rather, it suggests that the effect of object affordance on action execution depends on the concurrent action intention and the relation between depicted hand posture and required motor action. Experiment 2 shows consequently that ideomotor compatibility effects between perceived and performed actions (Brass et al., 2000) modulate the processing of action-related object features and its impact on the motor system.

However, we cannot exclude at this point that the interaction between object compatibility and posture compatibility originates from interference at the perceptual stage of stimulus identification and is not driven, as interpreted earlier, by stimulus–response

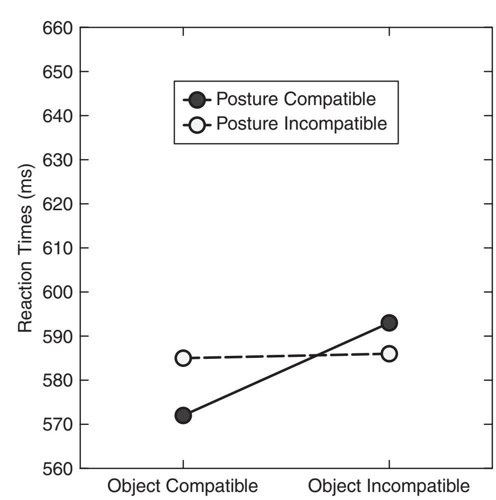

Figure 4. Mean response latencies of the grasping movements in Experiment 2 as a function of the factors object compatibility and posture compatibility.

relations. It might be possible that effects of object perception on the grasping actions emerge only if the object is part of a meaningful grasping action scenario in which the depicted hand posture is shaped appropriately to grasp an object (i.e., a small object next to a precision handgrip or a large object next to a power handgrip). The observed interaction would in this case merely be the result of facilitated processing of objects presented next to appropriately shaped hands, which would reflect an effect of visual familiarity based on people's experiences in action observation. To control for this alternative explanation, we conducted another experiment.

Experiment 3

In Experiment 3, we aimed to examine the origin of the interaction between posture and object compatibility in greater detail. We tested in particular whether the interference effect observed in Experiment 2 reflected an overlap between action stimulus and response features (ideomotor stimulus–response compatibility) or whether it was driven by an intrastimulus consistency of two stimulus features, that is, the fit of the depicted grasping hand and the object size (stimulus–stimulus congruency effect; see Kornblum et al., 1990). A straightforward way to disentangle these two explanations is to minimize the ideomotor compatibility between observed and executed actions. To do so, we modified the required action responses and instructed participants to perform pointing movements, which are, in contrast to the grasping actions in the previous experiment, unrelated to the depicted hand postures. If the observed interference effect in Experiment 2 reflects a facilitated perceptual processing of consistent action scenarios in which the grip size of the presented hand posture fits the object size, RT effects should be independent of the required type of motor response and thus also be present for pointing movements. On the contrary, no difference should be expected in pointing latencies if the observed effects depend on the compatibility between the selected responses and the depicted action scenarios.

Method

Participants. Twenty-four right-handed students of Radboud University Nijmegen took part in the experiment in return for €4.50 ($6.39) or course credit. All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study.

Setup, stimuli, and procedure. The experimental setup, stimuli, and procedure were almost identical to those of Experiment 2. The only modification was that participants had to indicate their judgments by pointing movements. That is, depending on the semantic category of the depicted object, participants were required to point either to the small top or to the large bottom part of the manipulandum. The actions were executed in a training phase until participants attained sufficient expertise. Half of the participants pointed to the small top cylinder when viewing a natural object and to the large bottom cylinder when viewing a manmade object. The response mapping was reversed for the other participants.

Data acquisition and design. The data acquisition and experimental design were identical to those of Experiment 3. Because pointing actions were not related to the hands and objects, responses could not be classified as object or posture compatibility. We therefore analyzed the latencies with respect to possible intrastimulus effects of the congruency between the depicted hand posture and the size of the object (i.e., stimulus congruency).

Results

The anticipation rate was less than 1%; incorrectly performed actions occurred in only 2.2% of the trials. A repeated measures two-way ANOVA on the mean RTs revealed no main effect for the factors stimulus congruency (congruent or incongruent), $F(1, 23) = 2.03$, $p > .1$, and motor response (pointing to the bottom or pointing to the top), $F(1, 23) = 3.07$, $p > .05$. Also, the interaction between the two factors failed to reach significance ($F < 1$). This finding suggests that semantic judgments and motor responses were not facilitated for stimuli in which the grip size of the depicted hand posture fit the object (667 ms) as compared with incongruent stimuli (674 ms).

To compare the congruency effects for grasping (Experiment 2) and pointing actions (Experiment 3) directly, we performed a mixed ANOVA with the between-subjects factor experiment and the within-subjects factor stimulus congruency. As the significant interaction between the two factors confirmed, $F(1, 46) = 3.90$, $p = .05$, stimulus consistency effects were present only in Experiment 2, $t(23) = 5.05$, $p < .001$, and not in Experiment 3, $t(23) = 1.42$, $p > .15$. Furthermore, RTs in Experiment 3 were on average slower (671 ms) than RTs in Experiment 2 (585 ms), $F(1, 46) = 10.80$, $p < .01$. It might consequently be possible that stimulus congruency effects emerge only if RT intervals are relatively short and vanishing congruency effects were thus the result of an overall RT difference. To exclude this possibility, we performed a RT distribution analysis and investigated the time course of a possible stimulus congruency effect in Experiment 3 (see Ratcliff, 1979). RTs for motor response and stimulus congruency conditions of each participant were rank ordered, divided into quintiles, averaged, and submitted to a repeated measures ANOVA. The interaction between the factors stimulus congruency and quintiles ($F < 1$) failed to reach significance, indicating an absence of stimulus congruency effects for the slow and the fast responses. We can therefore exclude that the vanishing of the congruency effect was the result of the overall RT difference between Experiments 2 and 3.

Discussion

When participants performed pointing movements, we observed no congruency effect between depicted object and depicted hand postures. This finding argues against the possibility that the outcome of Experiment 2 was driven by stimulus–stimulus congruency effect, that is, a facilitated perceptual processing of congruent action scenarios in which the grip size of the presented hand posture fitted the size of the object. We can therefore exclude that the modulation of object affordance effects by observed hand postures had a mere perceptual origin.

Our experiments demonstrate that the compatibility between observed and performed grasping actions modulates the perception and the cognitive effects of the object affordances. Interestingly, Experiment 2 revealed no main effect for the factor posture compatibility, that is, faster initiations of grasping responses consistent with the depicted hand postures. At first glance, this finding might be unexpected because several previous studies have reported the presence of ideomotor compatibility effects for motor response that are consistent with observed hand movements (Brass et al., 2000; Stürmer et al., 2000; but see also Vainio, Tucker, & Ellis, 2007). In contrast to these studies, the hands in Experiment 2's pictures were never presented alone without an object. Nevertheless, we can exclude that they were not processed because hand posture compatibility modulated the presence of object affordance effects. The lack of an ideomotor compatibility effect can be interpreted as an indication that participants processed the hand and the object as one integrated action scenario and not as two separate stimuli. Alternatively, the dominance of object affordance effects might be because the semantic categorization task required participants to focus their attention on the object and less on the depicted hand. This raises the question of whether both hand posture compatibility and object affordance effects emerge simultaneously while viewing an object and a hand that are not perceived as two related entries. In Experiment 4, therefore, we tested whether two independent stimulus–response compatibility effects for object and hand can be observed if they are presented as spatially separated visual stimuli that are not part of one action context.

Experiment 4

Experiment 4 investigated the presence of stimulus–response compatibility effects of the depicted object and hand posture under conditions in which they are not elements of one integrated object-directed action. The same pictures were presented as in the previous experiments. However, objects and hand postures were now presented at two separate locations on the screen so that they did not appear to be two related elements in one grasping action scenario. We expected that if objects and hands are perceived as two separate stimuli, RTs would reflect two independent effects, that is, an effect of the object affordance and an effect of ideomotor compatibility.

Method

Participants. Twenty-four right-handed students of Radboud University Nijmegen took part in the experiment in return for €4.50 ($6.39) or course credit. All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study. None of the students had participated in the other experiments.

Setup, stimuli, and procedure. The experimental setup, stimuli, and procedure were basically the same as in Experiment 2. The only modification was the arrangement of the hand and object stimuli on the screen. Instead of presenting the two pictures in spatial proximity to one another, object and hand posture were presented in the left and right visual field (4° eccentricity), respectively, so that the hand did not appear to approach the object (see Figure 3B). As in Experiments 2 and 3, the pictures of right hands were presented to the left of the object and left hands were presented to the right.

Data acquisition and design. The data acquisition and experimental design were identical to those of Experiment 2.

Results

The rate of anticipations was less than 1%. The error rate was 5.2%. The three-way repeated measures ANOVA (Motor Response × Object Compatibility × Posture Compatibility) of the mean RTs revealed significant effects for both compatibility factors. Object-compatible responses (627 ms) were initiated faster than object-incompatible responses (648 ms), $F(1, 23) = 23.85$, $p < .001$, and responses compatible with the depicted posture (633 ms) were initiated faster than the posture-incompatible responses (641 ms), $F(1, 23) = 3.95$, $p < .05$ (see Figure 5). Interestingly, the interaction of the two compatibility factors did not reach significance, $F(1, 23) = 1.2$, indicating that the effects of object and of posture compatibility occurred independently of one another and did not interfere.

Again, participants showed a tendency to initiate power grip responses (629 ms) faster than precision grip responses (645 ms), $F(1, 23) = 3.83$, $p < .07$. The two-way interactions between motor response and object compatibility and between motor response and posture compatibility were both significant, $F(1, 23) = 9.39$, $p < .005$, and $F(1, 23) = 11.46$, $p < .003$, respectively. These interaction effects indicate that both object and posture compatibility effects were larger for power grip responses (34 ms and 19 ms, respectively) than for precision grip responses (8 ms and 3 ms, respectively), $ts(23) = 3.32$ and 2.94, $ps < .05$.

To test whether the influence of the depicted hand posture on the object compatibility effect was different in Experiment 4 than in Experiment 2, in which object and hand posture were presented close together, we performed a between-experiments comparison. To this aim, we calculated the size of the object compatibility effects, defined as the RT difference between object-incompatible and object-compatible trials, for each participant in both experiments. We entered the resulting RT effects into a mixed design ANOVA with the between-subjects factor experiment (Experiment 2 or Experiment 4) and the within-subject factor posture compatibility. Besides the main effect of posture compatibility, $F(1, 46) =$

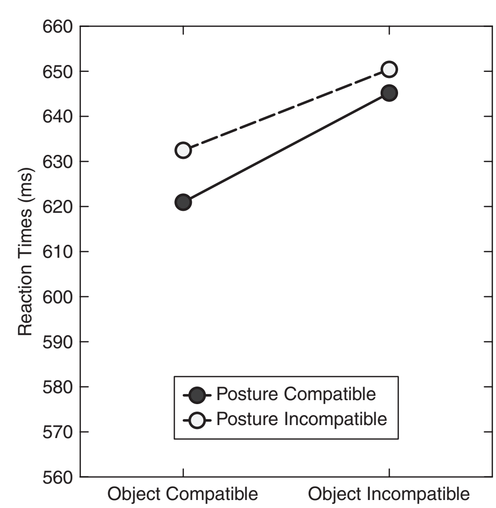

Figure 5. Mean response latencies of the grasping movements in Experiment 4 as a function of the factors object compatibility and posture compatibility.

11.49, $p < .001$, the analysis yielded a significant interaction between the two factors, $F(1, 46) = 4.34$, $p < .05$. Post hoc t tests showed that the depicted hand postures had an impact on the presence of the object compatibility effect only in Experiment 2 (object compatibility effect for hand-compatible trials, 21.4 ms; for hand-incompatible trials, 0.31 ms), $t(23) = 3.68$, $p < .001$, but not in Experiment 4 (18.3 ms vs. 23.4 ms), $t(23) < 1$.

Discussion

Experiment 4 demonstrates the presence of two independent stimulus–response compatibility effects, object affordance and hand posture, if both were presented simultaneously but as two separate stimuli. That is, grasping actions were initiated faster in response to pictures of objects affording a compatible grip and in response to pictures of compatible hand postures. More important, the results revealed that the stimulus–response compatibility effect of object and posture did not interact if the pictures were not arranged so that the hand appeared to approach the object. The lack of cross-talk under these circumstances shows that the relation between the hand posture and the object modulates the presence of object compatibility effects. As the comparison of the object compatibility effects in Experiments 2 and 4 confirmed, the perceptual processing of the object and hand posture interacted only if they were perceived as two integrated parts of one action scenario. This outcome points to the important role of the action context in object perception and the processing of object affordances.

General Discussion

Four experiments explored the cognitive interference between perception and action and investigated, in particular, the role of contextual information on the behavioral effects of perceived object affordances. As the analyses of stimulus–response compatibility effects revealed, perceived affordances of an object had an influence on the planning and execution of natural reach-to-grasp actions. This observation is in line with several previous studies showing that the perception of an object activates representations of motor actions that are best suited for a manipulation of the object (Glover et al., 2004; Phillips & Ward, 2002; Tucker & Ellis, 2001). More important, this study aimed to investigate the influence of the action context, that is, the influence of observation of others' actions on the processing of action-relevant object features. It thus extends the literature on object perception and action affordances in at least two aspects.

First, we demonstrated that the object affordance effects on motor response are modulated by the action context in which the object is perceived. We only found stimulus–response compatibility effects between object features and required motor responses when the object was presented close to the hand grasping posture so that they formed a meaningful grasping action (Experiment 2). We did not, however find effects of the object affordance if an object-inconsistent hand posture was presented. This interaction shows that object affordance effects strongly depend on the action context, that is, the observed action that is performed with the object, suggesting that object-related actions are not automatically activated in the observer. Interestingly, the compatibility effects could not be observed when participants executed finger-pointing movements (Experiment 3). We can consequently reject the alternative account of the outcome of Experiment 2 as a stimulus–stimulus congruency effect and exclude the possibility that object affordance effects were driven by a facilitated perceptual processing of congruent action scenarios in which the grip size of the presented posture fitted the size of the object. We therefore interpret the dependence of the object affordance effect on the depicted hand posture as evidence for an influence of contextual information on object processing. This outcome is in line with other studies showing that the associated functional object knowledge becomes activated only if people intend to use the object with that specific purpose (Bub & Masson, 2006; Lindemann et al., 2006) or if the object is perceived in an active action context (Tipper et al., 2006). We thence conclude that the activation of action representations and motor codes is not completely automatic and obligatory (see, e.g., Tucker & Ellis, 2001).

Second, this study is among the first to demonstrate the presence of object affordance effects in reaching and grasping components of natural object-directed grasping actions. So far, object affordance effects have mostly been reported only for button-press responses or simple finger movements that are involved in grasping actions (e.g., Derbyshire et al., 2006; Ellis & Tucker, 2000; Tucker & Ellis, 2001). The major advantage to using natural object-directed grasping action is the possibility of dissociating between effects in reaching and grasping components of motor response. Interestingly, object affordance effects were evident in both the onset of the reaching movements and the movement kinematics of the grasping. The effect in the movement latencies shows, in line with motor theories (Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001), that the intended grip size at the end of the movement is anticipated and planned before the hand has reached the target object. This interference between object perception and action intention clearly demonstrates that object affordance effects emerge at the level of motor planning. Also, the finding of an enlarged MGA indicates an interaction between object perception and action planning. The effect on the grasping kinematics, moreover, parallels research demonstrating effects of size-related semantic information on grasping actions (Gentilucci, Benuzzi, Bertolani, Daprati, & Gangitano, 2000; Glover et al., 2004; Lindemann et al., 2007). Glover et al. (2004) have shown that the modulation of the grip aperture by magnitude information reflects interference at the level of action planning. The kinematics effect in this study consistently provided additional support for our notion that the perception of action-relevant object features interferes only with action planning but not with motor control.

As mentioned before, the ideomotor theory suggests that action representations are activated when observing visual events that correspond to effects of own and others' motor actions (Hommel et al., 2001). With this study, we provide new support for this view by demonstrating that ideomotor compatibility effects are not restricted to simple finger movements and also emerge in connection with complex action scenarios and goal-directed reach-to-grasp movements. When the object and the hand grasping posture were presented far away from one another (Experiment 4), we found two effects. Observing a grasping hand facilitates the execution of similar grasping actions (i.e., ideomotor compatibility effect; Brass et al., 2000;

Stürmer et al., 2000), whereas observing a manipulable object primes the execution of the grasping action associated with it (cf. Tucker & Ellis, 2001). Interestingly, the behavioral effects of object perception and action observation have mostly been investigated in isolation. As this study now shows, object affordance and ideomotor compatibility effects can arise under certain conditions independently and do not necessarily interfere. This independence indicates that the mere perception of others' actions is not sufficient to modulate the processing of action-relevant object features and suggests that object and action observation interact only if both aspects are conceived as part of one meaningful action scenario (Experiment 2).

Taken together, these data argue against the view that visual objects automatically and obligatorily potentiate components of action they afford and rather provide evidence for the notion that the processing of action-relevant object features depends greatly on the contextual correspondence of perception and action. The finding that object affordance effects depend on the action context in which the object is perceived supports the idea of an intentional weighting of action-relevant dimensions in perceptual processing.

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Appendix A

Natural and Manmade Objects Presented in Experiment 1

Small objects affording a precision grip action: almond, brussels sprout, cranberry, garlic, grape, mushroom, nut, pepper, radish, string bean, clothespin, key, lighter, paperclip, pen, pencil, sharpener, screw, teaspoon, tweezers.

Large objects affording a power grip action: avocado, banana, carrot, cucumber, eggplant, leek, mango, pear, paprika, potato, brush, corkscrew, cup, hairbrush, hairdryer, hammer, knife, rake, saw, screwdriver.

Appendix B

Natural and Manmade Objects Presented in Experiments 2, 3, and 4

Small objects affording a precision grip action: almond, brussels sprout, cranberry, garlic, grape, mushroom, nut, pepper, radish, string bean, chess piece, clothespin, dart, hairspray, needle, paperclip, pushpin, sharpener, teaspoon, tweezers.

Large objects affording a power grip action: avocado, banana, carrot, cucumber, eggplant, leek, mango, pear, paprika, potato, book, bottle, cup, iron, joystick, key, soft drink can, tea box, teapot, thermos.

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