Object Manipulation and Motion Perception: Evidence of an Influence of Action Planning on Visual Processing

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In press: *Journal of Experimental Psychology: Human Perception and Performance.*
This manuscript may not exactly replicate the final published version.
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Abstract

Three experiments investigated the bi-directional coupling of perception and action in the context of object manipulations and motion perception. Participants prepared to grasp an X-shaped object along one of its two diagonals and to rotate it in a clock- or counterclockwise direction. Action execution had to be delayed until the appearance of a visual go signal, which induced an apparent rotational motion in either a clock- or counterclockwise direction. Stimulus detection was faster when the direction of the induced apparent motion was consistent with the direction of the concurrently intended manual object rotation. Responses to action-consistent motions were also faster when the participants prepared the manipulation actions but signaled their stimulus detections with another motor effector (i.e., with a foot response). Taken together, the present study demonstrates a motor-visual priming effect of prepared object manipulations on visual motion perception indicating a bi-directional functional link between action and perception beyond object related visuomotor associations.

Keywords: object manipulation, motion perception, perception-action coupling, motor-visual priming, embodied cognition

Introduction

Accumulating behavioral and neuropsychological research suggests a close and bi-directional link between perceptual and motor processes (see e.g., Hommel, Müsseler, Aschersleben, & Prinz, 2001). For instance, several cueing experiments have shown that visual images of graspable objects (Tucker & Ellis, 1998; Craighero, Fadiga, Rizzolatti, & Umiltà, 1998) or film sequences of actions of others (Brass, Bekkering, & Prinz, 2001; Vogt, Taylor, & Hopkins, 2003) prime the motor system and speed up the initiation of an action when the cue and the motor response are congruent (*visuomotor priming*). Interestingly, recent studies, however, report evidence for an effect of the opposite directionality, i.e., an impact of motor actions on visual processing (here referred to as *motor-visual priming*). Action-induced effects on vision have been observed in participants performing rather simple actions like button-press responses (Müsseler & Hommel, 1997; Wühr & Müsseler, 2001; Kunde & Wühr, 2004), pen movements (Zwickel, Grosjean, & Prinz, 2007), pointing movements (Deubel, Schneider, & Paprotta, 1998; Bekkering & Pratt, 2004; Linnell, Humphreys, McIntyre, Laitinen, & Wing, 2005), or changes in hand postures (Hamilton, Wolpert, & Frith, 2004; Miall, Stanley, Todhunter, Levick, Lindo, & Miall, 2006).

So far, only few studies reported motor-visual priming effects for more complex and natural motor behaviors like reaching for and grasping an object (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Fagioli, Hommel, & Schubotz, 2007; Symes, Tucker, Ellis, Vainio, & Ottoboni, 2008). For example, a study of 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 subject concurrently intends to perform. In their paradigm, differently oriented wooden bars had to be grasped without the aid of sight. A word cue informed the participants about the orientation of the bar and instructed them to prepare the corresponding grasping action. However, the actual execution of the prepared motor response had to be delayed until a visual go signal was presented. Craighero et al. (1999) reported faster response if the go signals afforded the same type of grasping response as the prepared action. Interestingly, this effect was also observed when the participants prepared a manual grasping response but signaled their detection of the visual stimulus with another motor effector. This finding has been interpreted as support for the idea of motor-visual priming, since it indicates that the preparation of a grasping movement facilitates the visual processing of stimuli that are associated with similar motor actions or that afford the same type of grip. Additional evidence for the idea of action-induced effects has been provided by studies comparing grasping and pointing movements showing that the intention to grasp an object selectively enhances the processing of visual object properties such as size (Fagioli et al., 2007) or orientation (Bekkering & Neggers, 2002; Hannus, Cornelissen, Lindemann, & Bekkering, 2005). Thus, the literature provides several examples indicating that the planning of grasping actions automatically modulates visual attention toward those object features and dimensions that are relevant for the selection and programming of that particular motor response. It is however unclear whether action-induced effects of grasping actions are restricted to these visuomotor associations between intrinsic object properties and afforded grip.

Surprisingly, research investigating the interaction between perceptual and motor processes in grasping has not paid much attention to the fact that grasping actions in everyday life are predominately instrumental and directed toward an action goal[1] that implies a manipulation of the object. For instance, depending on whether we wish to open or close a faucet we grasp it with the intention to rotate it afterwards in a clock- or counterclockwise direction. Although it is widely recognized that the intended manipulation of an object plays a very crucial role in the selection and preparation of the initial reach-to-grasp movement (e.g., Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001), the role of action goals for the presence of motor-visual priming effects has not yet been investigated.

Since each object manipulation implies a visually perceivable movement and taking into account the importance of visual feedback for the control of motor actions (cf. Castiello, 2005; Glover, 2004), it is plausible to assume that especially the perceptual processing of visual motions is characterized by a close perception-action coupling. As yet, very little is known about the interference between action and motion perception. It has been shown, for example, that the perception of moving objects automatically activates responses that correspond spatially to the direction of the perceived motion (Michaels, 1988; Proctor, Van Zandt, Lu, & Weeks, 1993; Bosbach, Prinz, & Kerzel, 2004). However, the only indication for an effect of the reversed directionality, which is an impact of action planning on motion perception, is coming from the finding of biased motion judgments while action execution. For example, Wohlschläger (2000) asked participants to indicate the direction of ambiguous apparent motion displays while they were turning a knob either clock- or counterclockwise. He observed that participants tend to judge the ambiguous rotations in the direction of their currently performed action and interpreted this as evidence that motion perception is biased in the direction of the produced movement. However, it cannot be excluded that the effects on directional judgments may have been caused by a guessing bias in perceptually unclear situations. Interestingly, Zwickel et al. (2007) reported recently that under some conditions also the opposite action-induced effect, namely a contrast effect between production and perception of movement directions, can be observed. Taken together, both findings suggest a close coupling between concurrent action execution and motion perception. However, it is still an open question whether perceptual processing of motions is likewise modulated by motor intentions and by merely prepared but not yet executed motor responses, as it known for static object perception (e.g., Craighero et al., 1999).

The aim of the present study was to investigate motor-visual priming in the context of object manipulation actions and to examine whether perceptual effects of grasping actions go beyond the processing of objects properties. Based on the considerations outlined above, visual motion perception provides a likely candidate for a domain which is sensitive to motor preparation. Thus, we conducted three behavioral experiments to test the idea that planning of an object manipulation affects perception of visual motions. We hypothesized that the intention to manipulate an object (e.g., to rotate an object) facilitates the processing of visual motions (e.g., a rotational motion on a computer screen) in the same direction as the prepared action.

Experiment 1

Experiment 1 investigates the interaction between the object manipulation actions and visual motion perception. We asked participants to reach out and grasp an object and to subsequently rotate it in a clockwise (CW) or counterclockwise (CCW) direction (see Figure 1). Similar to the delayed-grasping paradigm proposed by Craighero et al. (1999), it was instructed to prepare the object manipulation in advance and to delay its execution until the appearance of a visual go signal. The go signal was either a tilted bar that afforded the same type of grip as the prepared action involved or the orthogonal grip. Importantly, before the go signal appeared a horizontal or a vertical bar was shown. Due to this initial stimulus, the onset of the go signal induced an apparent rotational motion of 45° in either a CW or CCW direction (see Figure 2a). In some trials, a solid circle was presented as go signal. These trails served as control condition, because a circle is not associated with one of the two required initial grips in the experiment and its appearance did not induce any apparent motion. Assuming that the participants prepare the actual manipulation before the onset of the reach-to-grasp movement, we predicted a facilitated processing of the rotational motions in the same direction as the intended object rotation.

Method

Participants

Thirty students from the Radboud University Nijmegen participated in exchange for 4.50 Euros or course credits. All were naive to the purpose of the study, had normal or corrected-to-normal vision and were free of any motor problems that could have affected their task performance.

Insert Figure 1 and 2 about here

Apparatus

Participants were required to manipulate an X-shaped object (manipulandum; Figure 1b) consisting of two perpendicularly intersecting wooden bars (8 cm × 1.1 cm × 5 cm each) mounted on a base plate (30 cm × 15 cm). The manipulandum could be rotated around its crossing point with the rotation axis being parallel to the Cartesian z-axis. Owing to small pegs underneath the X-shaped object and holes inside the base plate, the manipulandum clicked into place after rotating it for 90°.

A small pin placed on the base plate at a distance of 15 cm from the manipulandum's rotation axis marked the starting position for the grasping movements. The manipulandum was oriented such that the both crossing bars were aligned 45° diagonally to the subject's midsagittal plane and positioned behind a wooden screen (44 cm × 45 cm) allowing the participants to reach it comfortably with their right hand but obscuring it and their hand from view (Figure 1a).

Stimuli

All stimuli were presented in the center of a computer screen that was placed at a viewing distance of approximately 70 cm in front of the participants. A black horizontal or vertical black bar (visual angle of 4.1° × 1.3° or 1.3° × 4.1° respectively) was presented as initial stimulus that was visible until the go signal appeared. A blue or yellow cross (0.9° of visual angle) on top the bar served as action cue to indicate the required motor response.

In the rotation condition, the go signals consist of bars in the same color and size as the initial stimuli. They were however tilted from the vertical for either -45° or +45° and afford thus the same type of grip (see below) as the currently prepared action involved (grip-consistent) or they afforded the orthogonal grip (grip-inconsistent). Since the go signals were presented at the same location as the initial stimuli an apparent rotational motion was induced by the appearance of the tilted bars (see Figure 2a for an illustration). For example, the presentation of a +45° tilted bar resulted in an apparent CW motion if the initial stimulus was oriented vertically and in a CCW motion if it was oriented horizontally. That is, depending on the required motor response, the onset of the go signal inducted either a rotational motion in the same (rotation-consistent) or opposite direction (rotation-inconsistent) as the currently prepared object manipulation. A solid circle subtending a visual angle of 2.7° was used as control condition.

Procedure

Participant performed a short training block prior to the actual experiment, in which they practiced to grasp and rotate the manipulandum without vision. The experimenter demonstrated the two possible object manipulation actions and showed how to rotate the object for 90° in a CW and CCW direction. The manipulandum had always to be grasped along one of its two crossing bars, that is, either with the index finger at the top-left and thumb at the bottom-right leg (‘left grip’) or with the index finger at the top-right and thumb at the bottom-left leg (‘right grip’). Each rotation afforded a specific type of grip. The object had to be grasped for CW rotations with a left grip and for CCW rotation with a right grip. The object manipulations were only demonstrated and never verbally instructed. When a motor response was carried out incorrectly, the experimenter corrected the participants and again demonstrated the required action.

The experimental block was started, if participants were able to carry out the movements fluently without vision. Half of the participants were presented with the horizontal and the other half with the vertical bar as initial stimulus. Each trial began with a presentation of a gray cross projected on top of the initial stimulus. Participants were instructed to fixated their eyes on the cross and hold the start peg (starting position) with index finger and thumb. As soon as the hand was placed correctly at the starting position, the color of the cross changed to cue the action. The action cues remained visible for 2,000 ms. A blue cross indicated a left grasp and a 90° CW rotation, whereas a yellow cross prescribed a right grasp and a 90° CCW rotation. Importantly, participants were required to prepare the object manipulation but withhold from action execution. After a random interval (250-750 ms) the initial stimulus disappeared and the go signal was presented for the duration of 1,000 ms. Participant had to initiate their prepared motor response as soon as they detected the onset of go signal. After rotating the manipulandum they returned their hands to the starting position and the next trial started.

Design

Apart from 10 randomly chosen practice trials, the experimental block comprised 144 trials presented in a random order. They were composed of all possible combinations of the two manual responses (left grasp/CW rotation, right grasp/CCW rotation) and the three go signals (circle, bar tilted -45°, bar tilted +45°). The orientation of the initial stimulus (horizontal, vertical) was balanced between subjects.

Go signals could be considered as consistent or inconsistent with respect to the currently prepared grasping movement. Moreover, depending on the induced apparent rotation, each trial was either consistent or inconsistent with respect to the prepared object rotation. In the control condition (i.e., solid circle as go signal), the go signal was not associated with a specific type of grip and did not induce any apparent motion. For participants with the horizontal bar as initial stimuli, all grip-consistent go signals induced a rotation-consistent visual motion, while for the vertical bar group, apparent rotation-consistent motions were only induced by grip-inconsistent stimuli.

Data acquisition and analysis

Hand movements were recorded with a sampling rate of 100 Hz using an electromagnetic position tracking system (miniBIRD 800^{TM}, Ascension Technology Corporation). Three sensors were attached to the thumb, index finger, and wrist of the participant's right hand.

Hand response latencies were determined offline. We applied a fourth-order Butterworth lowpass filter with a cut-off frequency of 10 Hz on the raw data. The reaction times (RT) were determined by calculating the time intervals between the stimulus onsets and the reach movement onsets. Reach onset times were defined as the moments when the tangential velocity of the index-finger sensor first exceeded a threshold of 10 cm/s and remained above this level for the minimum duration of 200 ms.

In all experiments reported here, anticipation responses (responses ahead of go signal onset and RTs<150 ms), missing responses (no reactions and RTs>800 ms) and incorrect actions (e.g. wrong grip, cessations of movement while reaching, incorrect rotation direction) were considered errors and excluded from the statistical analyses. A type-I error rate of α=.05 was used in all statistical tests. Whenever appropriate, pairwise post-hoc comparisons were conducted using the Bonferroni procedure.

Results

Anticipations occurred in 14.9% of all trials (4.9% of RTs<0 ms; 10.4% of RTs <150 ms). The missing rate was below 1%. 8.4 % of the actions were performed incorrectly.

We applied a repeated measures multivariate analysis of variance (MANOVA)[2] with the within-subject factors Manual Response (left grasp/CW rotation, right grasp/CCW rotation) and Rotation Consistency (consistent, inconsistent, control) and the between-subject factor Initial Stimulus Orientation (horizontal, vertical) on the mean RT data (see Table 1). As hypothesized, the analysis revealed a main effect for the factor Rotation Consistency, $F(2, 27) = 9.75$, $p<.001$, partial $\eta^2=.42$. All other effects failed to reach significance. Post-hoc *t*-tests yielded shorter RTs to go signals inducing rotation-consistent motions (322 ms) as compared to go signals inducing rotation-inconsistent (345 ms), $t(29)=-4.16$, $p<.001$, or no motions (control condition: 338 ms), $t(29)=-3.31$, $p<.01$. Moreover, as a separate one-way MANOVA with the factor Grip Consistency (grip-consistent, grip-inconsistent, control) indicated, there were no significant differences between responses to grip-consistent stimuli (331 ms), grip-inconsistent stimuli (336 ms) and stimuli that did not afford a specific grip (control condition: 338 ms), $F(2, 28)<1$.

Insert Table 1 and Figure 3 about here

In order to compare the effects of Rotation and Grip Consistency directly and to see whether the two factors interacted, we calculated for each subject the deviations of the mean RTs to the grip-consistent and grip-inconsistent bars from the mean RT in the control condition. The resulting RT effects were submitted to a univariate analysis of variance (ANOVA) with the factors Rotation Consistency (consistent, inconsistent) and Grip Consistency (consistent, inconsistent). The main effect for Rotation Consistency was significant, $F(1, 56) = 9.61$, $p<.003$, partial $\eta^2=.15$, whereas there was no effect for Grip Consistency, $F<1$. Mean RT effects are depicted in Figure 3 and indicate a positive effect (15 ms) for consistent rotational motions relative to the control condition and a negative effect (-7 ms) for rotational motions. Interestingly, the two factors did not interact, $F<1$, showing that the Rotation Consistency effect was independent from the orientation of the go signal.

Discussion

Experiment 1 demonstrates that stimulus detections were sped up when go signals induced apparent rotational motions in the same direction as the currently prepared object manipulation. This rotation consistency effect reflects an interference effect between object manipulation and visual motion perception and indicates in particular a perceptual benefit for consistent visual motion. We interpret this finding as evidence for an impact of action planning on the perceptual processing and as support for the notion of motor-visual priming effects in motion perception.

Interestingly, if the apparent motions were inconsistent with the prepared action stimulus detections tend to be slower as compared to the control condition. This may reflect an impaired processing of inconsistent rotational motions. Although the results clearly demonstrate an interaction between object manipulation and visual motion perception, it remains unclear whether indeed both a positive and a negative effect—i.e., a facilitated processing of consistent and an impaired processing of inconsistent motions—contribute to the presence of motor-visual interactions. It is important to consider that the interpretation of positive and negative reaction time effects strongly depends on the used baseline condition.

As described above, the control condition was implemented by varying the go signal. We choose for this procedure, because the solid circle presented as go signal could serve as control condition for rotation consistency effects as well as for grip consistency effects. However, when trying to separate positive and negative impact of action planning on motion perception, it might be problematic to interpret the control condition of Experiment 1 as an appropriate neutral baseline estimate, because the control condition differed from the rotation conditions not only with respect to the induced visual motion but also with respect to the presented stimuli. That is, due to the different visual properties of the go signals, it is unclear whether the results allow a conclusion about the presence of positive and negative motor-visual priming. We designed thus a second experiment to clarify this question.

Experiment 2

Experiment 2 focused on the rotation consistency effect and introduced another no rotation condition that provides a better baseline estimate for an analysis of positive and negative motor-visual priming effects. Again, we presented bars in different orientations as initial stimuli and as go signals. In contrast to the previous experiment, however, trials without apparent motion were now implemented by a variation of the initial stimulus and not by a variation of the go signal. That is, a no rotation trial started with the presentation of a solid circle followed by a tilted bar as go signal (see Figure 2b). Since all go signals were tilted bars, the three experimental conditions (rotation-consistent, rotation-inconsistent, no rotation) different only with respect to the induced apparent rotational motion. The no rotation condition of Experiment 2 can be consequently interpreted as a measurement for a neutral baseline that separates the positive and negative effects of action planning on motion perception.

Method

Participants

Fifteen students from the Radboud University Nijmegen participated in exchange for 4.50 Euros or course credits. All were naive to the purpose of the study, had normal or corrected-to-normal vision and were free of any motor problems that could have affected their task performance.

Apparatus, stimuli and data acquisition

The apparatus, stimuli and data acquisition were the same as in Experiment 1.

Procedure

Also the procedure was basically unchanged. Only the sequence of events in the no rotation condition without apparent motion was modified as depicted in Figure 2b. The solid circle did not serve as go signal and was rather presented in some of the trails as initial stimulus. The go signal was a bar either tilted -45° or +45°. In order to minimize the amount anticipation responses, we presented a sinusoid 4400-Hz tone (200 ms duration) as negative feedback when participants responded before the onset of the go signal.

Design and analysis

In contrast to Experiment 1, the initial stimuli (horizontal bar, vertical bar, circle) were varied blockwise within subjects. Each of the three experimental blocks comprised 72 trials composed of all possible combinations of the two manual responses (left grasp/CW rotation, right grasp/CCW rotation) and the two types of go signals (bar tilted -45°, bar tilted +45°). All blocks started with 10 randomly chosen additional practice trials, which were later not analyzed. The order of blocks was permutated across participants. Depending on the initial stimulus, the onset of the titled bar induced an apparent rotational motion that was consistent or inconsistent with the prepared action or induced no rotation (neutral no rotation condition).

Since go-signals in all three rotation conditions were either consistent or inconsistent with the prepared grip, we obtained from each subject a mean RT for all combinations of the factors Rotation Consistency and Grip Consistency. The influence of both factors could be therefore directly tested without calculating RT effects.

Results

Participants the tendency to response before the go signal onsets was much smaller (0.9% of RTs<0 ms and 3.3% of RTs<150 ms) than in Experiment 1 reflecting the presence of the negative feedback in the case of anticipation responses. Again, the rates of missings (<1%) and incorrect responses (4.4%) were low.

Insert Table 2 and Figure 4 about here

Mean RTs (see Table 2) were submitted to a repeated measures MANOVA with the within-subject factors Manual Response (left grasp/CW rotation, right grasp/CCW rotation),

Rotation Consistency (consistent, inconsistent, neutral no rotation) and Grip Consistency (consistent, inconsistent). The analysis revealed a non-significant trend for the factor Manual Response, *F*(1, 14) =3.46, *p*=.08 , partial η^2=.12, indicating the slight tendency to initiate CCW object manipulation actions (297 ms) faster than CW object manipulations (305 ms). Importantly, we observed an effect for the Rotation Consistency, *F*(2, 13) =5.56, *p*<.05 , partial η^2=.46. The detections of apparent rotational motions consistent with the prepared action were faster (292 ms) as compared the detections of inconsistent rotational motions (309 ms), *t*(14)=-3.44, *p*<.01. RTs in rotation-inconsistent trials and neutral no rotation trials (301 ms) did not differ significantly, *t*(14)=1.05. The factor Grip Consistency did not reach significance, *F*(1, 14) =1.53. There were no interaction effects.

For a better comparison of the results with the outcome of Experiment 1, we additionally calculated the mean RT effect of the presentation of the tilted bars for each subject and each condition (see Figure 4 for means). Again, the 2 (Grip Consistency) x 2 (Rotation Consistency) MANOVA yielded only an effect for Rotation Consistency, *F*(1, 14) =11.90, *p*<.01 , partial η^2=.45, all other *F*s<1, indicating a positive effect (8 ms) for rotation consistent motions as well as a negative effect (-9 ms) for rotation inconsistent motions.

Discussion

Experiment 2 provides additional support for the presence of motor-visual priming of motion perception. Importantly, the results confirm furthermore the presence of a positive as well as a negative motor-visual priming of motion perception. Both effects were comparable in size suggesting that prepared motor actions facilitate the processing of consistent visual rotational motions on the one hand and impaire the processing of inconsistent motions on the other hand.

We have interpreted the observed rotation consistency effect in Experiment 1 and 2 as an impact of action planning on the perception of visual motions. However, it is important to notice that the execution of the object manipulation actions in the first two experiment was directly coupled to the detection of the visual motions. As a result, it might be possible that the outcome was driven by a stimulus-response priming. That is, in contrast to an action-induced effect on motion perception, the RT differences could reflect an accelerated initiation of manual actions comprising an object rotation that is consistent with the perceived visual motion. Such visuomotor priming (Vogt et al., 2003), however, would represent an effect of reversed directionality as the hypothesized effect of motor-visual priming. Since this alternative account cannot be ruled out at present, we conducted a third experiment that distinguishes between the two conflicting explanations.

Experiment 3

The aim of Experiment 3 was to examine the origin of the interference between object manipulation and motion perception. In particular, we sought to provide direct evidence for the notion that the observed rotation consistency effect reflects a motor-visual priming on the level of motion perception rather than a stimulus-response priming on the level of response execution. To test this assumption, we introduced a second motor response. That is, participants prepared again one of two object manipulation actions. In contrast to the previous experiments, however, the onset of the second visual stimulus (i.e., the apparent visual motion) did not prompt the execution of the manual action. Participants were rather instructed to signal the detection of the stimulus by a speeded foot pedal response. The object manipulation had to be performed later in the trails in response to an auditory signal.

The rationale of Experiment 3 was as follows (cf. Craighero et al., 1999; Fagioli et al., 2007): if, as hypothesized, the preparation of a manual action affects the perceptual processing of visual motions, we should observe a priming effect also for stimulus detections indicated by another effector system (in this case the foot). By contrast, if the alternative explanation holds, that is, if the perception of visual motions had influenced the initiation of manipulation actions in the same or opposite direction, we expect to find no priming effect in the latencies of foot pedal responses, because foot response do not share any spatial features with the perceived stimulus rotation.

Method

Participants

Fifteen students from the Radboud University Nijmegen participated in exchange for 6 Euros or course credits. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Apparatus, stimuli and data acquisition

The apparatus and stimuli were identical to those used in Experiment 1. A sinusoid 900-Hz tone (150 ms duration) was used as auditory go signals to trigger the execution of the object manipulations. To record the foot responses we placed a foot pedal (conventionally used by percussionists to play the bass drum) under the table and attached a motion-tracking sensor to the end of the pedal's drumstick (17.5 cm long). When the pedal had been pressed a sinusoid 440-Hz tone (50 ms duration) sounded as feedback and indicated the correctness of the response. In the case of an anticipation response, a negative auditory feedback was given (4400 Hz lasting 200 ms).

Data acquisition was the same as in previous experiments with the exception that we used a fourth motion-tracking sensor to measure the foot pedal responses. The same criterion as used for the hand responses (i.e., velocity threshold of 10 cm/s) was chosen to determine the foot response latencies.

Procedure and design

The procedure was similar to Experiment 1. A horizontal or vertical bar was presented as initial stimulus. The object manipulations were pre-cued by colored crosses. Again, the second visual stimulus was a bar tilted -45° or +45° or a solid circle (see Figure 1a and

Experiment 1 for presentation times). However, it did not serve as go signal for the manual actions. Participants were rather instructed to make a foot response (with their right foot) as soon as the second stimulus appeared. 600 ms after pressing the foot pedal, the auditory go signal sounded and indicated the initiation of the prepared object manipulation.

Experiment 3 was divided into four blocks of 48 trials each. As in Experiment 2, the orientation of the initial stimulus was varied blockwise within subjects. Half of the participants saw a horizontal bar in blocks 1 and 3 and a vertical bar in blocks 2 and 4 and for the other half the order reversed.

Results

4.7% of the foot responses were excluded from the analysis due to an incorrect execution of the delayed object manipulation. Anticipatory foot responses occurred in only 2.6%.

The MANOVA of the foot RTs (see Table 1 for means) with the within-subject factors Manual Response (left grasp/CW rotation, right grasp/CCW rotation), Rotation Consistency (consistent, inconsistent, control) and Initial Stimulus Orientation (horizontal, vertical) revealed a simple main effect for Rotation Consistency, $F(2, 13)=4.34$, $p<.05$, partial $\eta^2=.40$. Post-hoc *t*-tests yielded shorter RTs for foot responses to visual motions consistent with the planned object manipulation (320 ms) than for foot responses to inconsistent motions (332 ms), $t(14)=-3.08$, $p<.01$, or control signals (332 ms), $t(14)=-3.30$, $p<.01$. Additionally, there was a trend to an interaction between the factors Manual Response and Rotation Consistency, $F(2, 13)=3.0$, $p=.08$, partial $\eta^2=.31$, which reflects the tendency to smaller rotation-consistency effects when a left grasp and CW rotation was required. There were no further significant effects, all *F*s<1.8.

Insert Figure 5 about here

The MANOVA testing for grip consistency effects yielded no differences between grip-consistent (328 ms), grip-inconsistent (325 ms) and control stimuli (331 ms), $F<1$. RT effects were calculated and entered into a 2 (Grip Consistency) x 2 (Rotation Consistency) MANOVA (see Figure 5 for means). There was no effect for Grip Consistency, $F(1, 14)<1$, but a significant effect for Rotation Consistency, $F(1, 14)=5.46$, $p<.05$, partial $\eta^2=.28$, indicating an average positive effect (8 ms) for consistent rotational motion.

Discussion

The foot-response latencies of Experiment 3 reveal the same rotation consistency effect as reported in Experiment 1 and 2. That is, faster foot responses were observed if the apparent visual motions were consistent with the prepared manipulation action. Due to the fact that the signaling of the visual motions took place before the manual action had to be executed and since the foot responses were unrelated to the stimuli and apparent motions, we can exclude the existence of stimulus-response priming at the level of response initiation. Rather, the foot response latencies clearly indicate a facilitated perceptual processing of visual motions consistent with the concurrently intended motor act. The outcome of Experiment 3 provides therefore strong support for the notion of motor-visual priming of object manipulations on motion perception.

General Discussion

The present study investigates motor-visual priming in the context of object manipulation actions and provides evidence for the presence of action-induced effects on visual motion perception. In three experiments, we demonstrate that participants who prepared themselves to grasp and rotate an object detect faster the onset of a visual stimulus if it induced an apparent visual motion in the same direction as implied by the intended manipulation action. Importantly, effects on motion perception also emerged if participants indicated their stimulus detections by pressing a foot pedal, that is, by a motor response unrelated to the apparent visual motion and the intended manual action. This observation clearly rejects the possibility of stimulus-response priming effects and provides straightforward evidence for a modulated visual processing as the result of prepared object manipulation actions. We argue therefore that the reported effects of rotation consistency reflect a motor-visual priming. The pattern of priming effects suggests moreover a positive impact of action planning on the detection of consistent visual motion as well as a negative action-induced effect on the perception of inconsistent motions. That is, action preparation seems not only to facilitate the detection of action consistent motions but also to impair the processing of action inconsistent motions.

Previous research has shown that the intention to grasp an object selectively enhances the visual discrimination of the perceptual dimensions size and orientation, which are relevant for the programming of reach-to-grasp movements (Craighero et al., 1999; Bekkering & Neggers, 2002; Hannus et al., 2005; Symes et al., 2008). Noteworthy, it is known from studies on object perception that these two stimulus dimensions are automatically associated with specific types of motor responses (Ellis & Tucker, 2000; Tucker & Ellis, 1998). The present experiments now demonstrate a motor-visual priming effect that goes beyond the process of grip selection and direct visuomotor transformation. Our finding of motor priming of visual motions provides thus new evidence for a bi-directional coupling of perception and action. It substantially extends previous research at least in two aspects:

First, we investigated the question of motor interference in the context of natural goal-directed manipulation actions and demonstrate that action-induced effects also emerge when participants prepare a short sequence of motor movements such as the reaching, grasping and turning of an object. So far, research in this field has focused mostly on rather simple and one-dimensional motor responses like, for instance, button press responses or mere grasping movements without object use (Müsseler & Hommel, 1997; Wühr & Müsseler, 2001;

Craighero et al., 1999; Hannus et al., 2005; Fagioli et al., 2007). The major advantage of the presented object manipulation paradigm is that it allows a direct investigation of action goals and the actual intended distal effects in the environment. Notably, reaction time effects found in the reaching of the object were driven by a movement that had to be performed at the end of motor sequence (i.e., the object rotation). This indicates not only that participants planed the manipulation of the object before the reach-to-grasp movement was initiated. Most importantly, it shows very clearly that the preparation of a motor behavior, which has not yet been executed, has an impact on perceptual cognitive processes. The interference between intended manipulations and motion perception provides therefore strong support for the idea of action-induced effects. Interestingly, in contrast to action-induced effects reported for mere reach-to-grasp movements (e.g., Craighero et al., 1999), the performance to detection stimuli affording the same type of grip as currently prepared was fully unaffected if participants planned to grasp the object in order to manipulate it afterwards. Apparently, the nature of the intended action goal determines which stimulus features are primed in the perceptual processing. This finding is in line with the idea that action planning represents a goal-driven process that involves an anticipation of the desired action effects at a sensory level (often referred to as the idea of ideomotor action; see e.g., Greenwald, 1970; Stock & Stock, 2004). We suggest accordingly conceptualizing the observed priming effects of object manipulation as perceptual resonance resulting from motor intentions (Schütz-Bosbach & Prinz, 2007; Rueschemeyer, Lindemann, van Elk, & Bekkering, in press).

Second, the interaction between object manipulations and motion detection shows that effects of action planning are not restricted to the perceptual processing of intrinsic object properties. Although there is evidence that visual motions facilitate the selection of compatible motor responses (Bosbach et al., 2004), to date only very little was known about the reversed effect. A first indication for action-induced effects on motion perception has been provided by Wohlschläger (2000) showing that participants' direction judgments of ambiguous apparent motions are systematically biased toward the direction of a simultaneously performed turning action (but see also Zwickel et al., 2007, for the finding of contrast effects). Importantly, this finding has been interpreted as evidence for a close coupling between concurrent action execution and motion perception. The present study now demonstrates that perceptual processing of motions is already modulated as the result of motor intentions and mere action preparation. It is furthermore important to notice, that the interpretation of the effects reported by Wohlschläger (2000) in terms of a primed perceptual processing is potentially problematic, because differences in judgments of ambiguous motion displays are likely to reflect a guessing bias in perceptually unclear situations. With our findings of effects in the stimulus detection times, we can exclude the possibility of judgment biases and provides thus in first time unambiguous empirical evidence for the notion that motor behavior affects the perceptual processing of visual motions.

Another important advantage of the suggested object manipulation paradigm is that it controls for potential confounds in earlier studies on motor-visual priming. As mentioned above, Craighero et al. (1999) was one of the first to reported motor-visual priming effects of reach-to-grasp movements. In contrast to the present study, they required participants to grasp objects positioned in different orientations and observed faster responses when the go signals afforded the same type of grip as the target object. Since motor actions were fully determined by the orientation of the target object, it was unclear whether the stimulus processing interacted indeed with the prepared response or with the cognitive representation of the object. Moreover, it is important to note that target objects and go signals in the consistent trials of the Craighero et al.'s experiments were always orientated in parallel. It might be therefore also possible that priming effects were driven by an overlap of visual properties (i.e., orientation or grip affordances) between the go signal and the target object (stimulus-object congruency). Due to the use of a single X-shaped manipulandum, we could ensure that the target object was always associated with both possible grasping responses and that its orientation is was held constant across all trials. Consequently, we can reject this alternative account and exclude that the observed reaction times effects were driven by the congruency between of the to-be-detected stimulus and to-be-grasped object.

The motor-visual priming effect—i.e., the facilitated processing of action-consistent motions and the impaired processing of action-inconsistent motions—seems to be in conflict with studies that reported an impaired accuracy in the identification of stimuli that share features with a prepared action (the so called action-effect blindness; Müsseler & Hommel, 1997; Wühr & Müsseler, 2001; Kunde & Wühr, 2004). For example, Müsseler and Hommel (1997) presented left- and right-pointing arrowheads shortly before the execution of a manual left or right keypress response and found impaired identifications for arrows that corresponded to the action (e.g., left-pointing arrowhead while planning a left keypress response). A crucial difference between the findings of motor-visual priming and action-effect blindness is that the former effect represents a RT difference in a speeded task, whereas the latter effect was found in the accuracy of unspeeded perceptual judgments. Although there is evidence that these methodological differences could account for the different perceptual effects (Santee & Egeth, 1982), we argue that the two findings are also from a theoretical point of view not in contradiction. The impaired accuracy in the perception of action-consistent stimuli has mostly been explained within a common coding framework (e.g., Theory of Event Coding; Hommel et al., 2001), which suggests that perception and action planning share cognitive codes that represent the features of both perceived stimuli and intended actions. It is furthermore assumed that the preparation of an action and its maintenance in short-term memory requires an integration of all associated and activated feature codes into one coherent action plan. Once a feature code becomes integrated it is bounded and, as a consequence, less available for another integration such as needed for the representation of a subsequent perceptual event. The likelihood that a certain feature code has to be integrated when an event is perceived depends on the feature's relevance for the task

(Hommel et al., 2001). That is, unattended task-irrelevant features might become activated but will not become part of any binding. In contrast to code integration, the mere activation of feature codes is assumed to facilitate the perceptual processing of events sharing these features. The planning of an action and the resulting integration of feature codes should therefore only cause inhibition effects on the attempt to integrate this code in a second cognitive representation (see also Müsseler, 1999, for a more detailed discussion). Taken together, it seems to be important to discern that the direction of the motion in the present paradigm was irrelevant to the participants' task and no short-term memory representation of the perceptual event had to be created for later recall. Due to this and in line with the theoretical considerations outlined above, action-effect blindness was not expected to occur. Instead, our data indicated a facilitation of motion detections sharing features with the intended action. Whether the encoding of visual motions into a short-term memory representation is impaired, as predicted by the Theory of Event Coding (Hommel et al., 2001), cannot be answered at this point and requests additional investigations of action effects on the accuracy of motion perception.

In sum, the present study demonstrates an action-induced effect of object manipulations on motion perception and provides thus evidence for a bi-directional link between motor and perceptual representations that cannot be explained by visuomotor associations of superficial motor-object characteristics. The motor-visual priming of motion perception originates from the relation between prepared actions (i.e., object manipulation) and expected action outcomes (i.e., rotational motions) and seems to suggests that visual perception is modulated toward changes in the environment representing a potential consequence of the currently intended motor act. Our finding can be thus interpreted in line with theories of ideomotor action (Stock & Stock, 2004), which hold that actions are represented and planned in terms of their sensory consequences. Accordingly, the reported motor-visual priming effect on motion perception provides empirical support for the notion that the planning of goal-directed actions is accompanied by an activation of sensory representations of the intended action consequences.

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We would like to acknowledge Boris van Waterschoot and Giovanna Girardi for their assistance in collecting the data. The present research is part of the Interactive Collaborative Information Systems (ICIS) project, supported by the Dutch Ministry of economic affairs, grant nr: BSIK03024.

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Footnotes

1. We use the term *action goal* to describe any kind of cognitive representation of changes in the environment that a person intends to achieve with a motor action. Behavioral goals can vary in terms of their remoteness, for instance, from a proximal goal like *grasping the faucet* to a more distal goals like *filling the bathtub with water* or *having a bath*. In this respect, action goals are here understood as proximal goals at the level of motor intentions (Jacob & Jeannerod, 2005).

2. We used the multivariate *F* test based on the Pillai-Bartlett *V* criterion for all within-subject factor analyses reported here (O'Brien & Kaiser, 1985).

Table 1

Mean Reaction Times (in ms) for Experiments 1 (Hand Response Latencies) and 3 (Foot Response Latencies). The Values in Parentheses Represent Standard Errors.

	Vertical initial stimulus			Horizontal initial stimulus		
	Rotation-consistent	Rotation-inconsistent	Control	Rotation-consistent	Rotation-inconsistent	Control
Experiment 1			*Hand response latencies*			
Left grasp & CW rotation	324 (21)	354 (24)	334 (20)	322 (21)	344 (24)	332 (20)
Right grasp & CCW rotation	337 (21)	339 (23)	354 (24)	307 (21)	340 (23)	330 (24)
Mean	*331 (21)*	*347 (23)*	*344 (22)*	*314 (21)*	*343 (23)*	*331 (22)*
Experiment 3			*Foot response latencies*			
Left grasp & CW rotation	328 (17)	341 (15)	330 (18)	327 (18)	322 (15)	323 (19)
Right grasp & CCW rotation	326 (16)	334 (19)	340 (19)	311 (16)	326 (19)	330 (15)
Mean	*327 (16)*	*338 (17)*	*335 (18)*	*320 (17)*	*324 (16)*	*327 (17)*

Note. CW=clockwise; CCW=counterclockwise;

Table 2

Mean Hand Response Latencies (in ms) for Experiments 2. The Values in Parentheses Represent Standard Errors.

	Grip-consistent			Grip-inconsistent		
Manual Response	Rotation-consistent	Rotation-inconsistent	Neutral no rotation	Rotation-consistent	Rotation-inconsistent	Neutral no rotation
Experiment 2						
Left grasp & CW rotation	298 (9)	310 (14)	295 (11)	297 (14)	324 (9)	305 (12)
Right grasp & CCW rotation	289 (9)	302 (15)	301 (13)	287 (12)	304 (13)	302 (13)
Mean	*293 (8)*	*306 (13)*	*298 (11)*	*292 (12)*	*314 (10)*	*304 (12)*

Note. CW=clockwise; CCW=counterclockwise;

Figure Captions

Figure 1. (A) Illustration of the experimental setup. Participants were seated in front of a computer screen. The starting position and the manipulandum were obscured from the participant's view by means of a wooden screen. (B) Illustration of the X-shaped manipulandum that could be rotated along the rotation axes indicated by *R*.

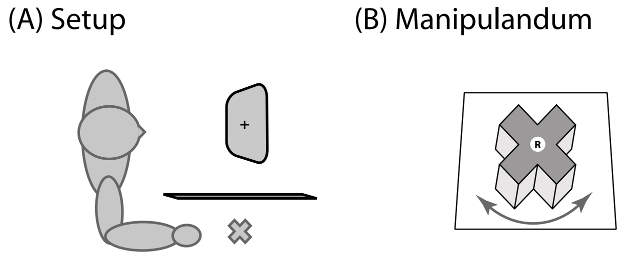
Figure 2. (A) Apparent visual motions caused by the sequence of events in Experiment 1 and 3. Depending on the orientation of initial bar (i.e., horizontal or vertical), the go signal (i.e., -45° or +45° tiled bar) induced an apparent rotational motion in a clock- or counterclockwise direction. The appearance of the solid circle (i.e., control condition) caused no apparent visual motion. (B) Sequence of events for the neutral no rotation condition in Experiment 2. The clock- and counterclockwise rotation conditions were identical to Experiment 1 and 3 (see subfigure A).

Figure 3. Mean RT effects (i.e., deviations from the control condition) of Experiment 1 as a function of the factors Rotation Consistency and Grip Consistency. Error bars represent standard errors.

Figure 4. Mean RT effects (i.e., deviations from the neutral condition) of Experiment 2 as a function of the factors Rotation Consistency and Grip Consistency. Error bars represent standard errors.

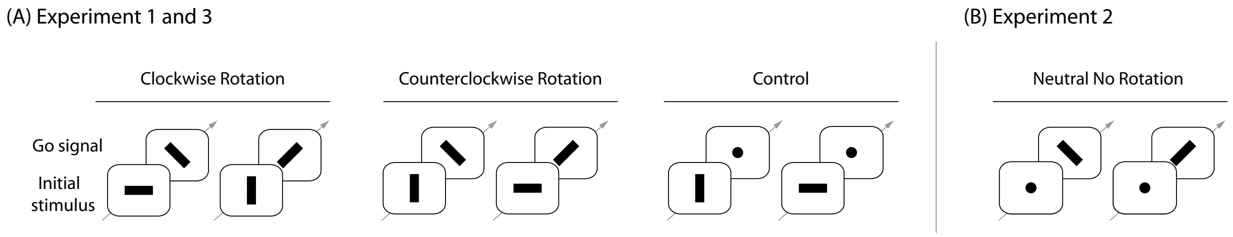
Figure 5. Mean effects (i.e., deviations from the control condition) in the foot response latencies of Experiment 3 as a function of factors Rotation Consistency and Grip Consistency. Error bars represent standard errors.

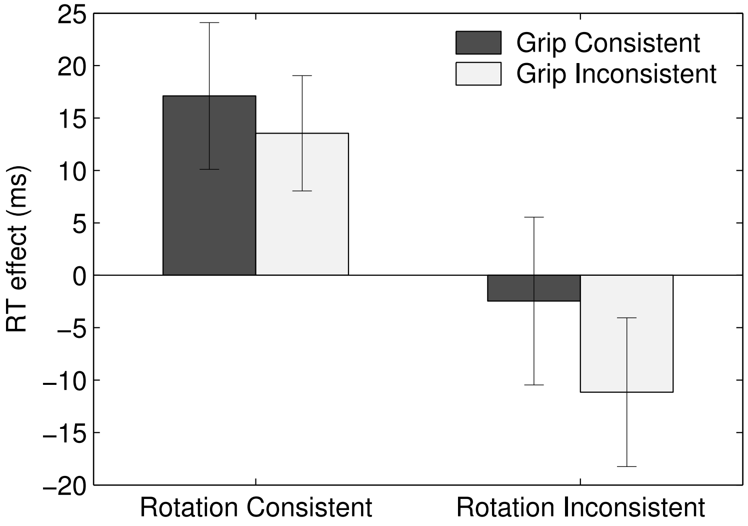
Object Manipulation and Motion Perception, Figure 1


(A) Setup

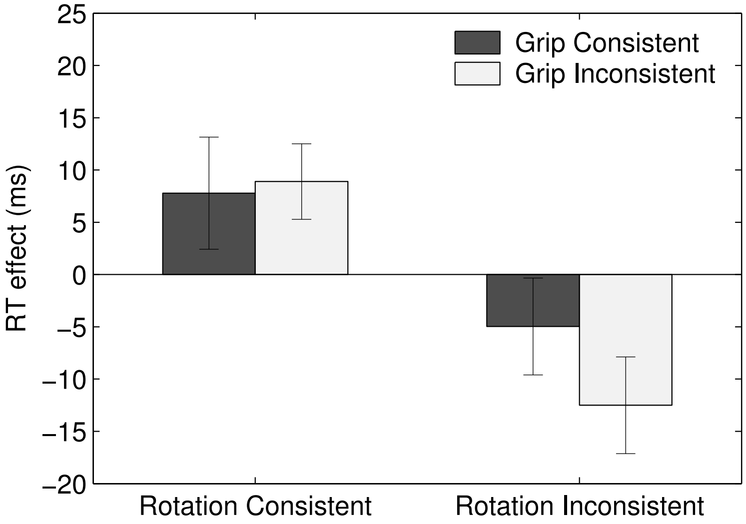
(B) Manipulandum

Object Manipulation and Motion Perception, Figure 2




25
20
15
10
5
0
−5
−10
−15
−20
RT effect (ms)
Grip Consistent
Grip Inconsistent
Rotation Consistent
Rotation Inconsistent

Object Manipulation and Motion Perception, Figure 4



Object Manipulation and Motion Perception, Figure 5