Chapter 2

Action and Visual Processing

Effects of Object Manipulation on Motion Perception
Abstract. Three experiments investigated the coupling of perception and action in the context of object manipulation. 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 was triggered by a visual go signal, consisting of a circle (neutral) or a tilted bar that afforded either the same (grip-consistent) or an orthogonal type of grip (grip-inconsistent) as the prepared action involved. Experiment 1 indicates that action preparation facilitates the detections of grip-consistent and end-state consistent stimuli. In Experiment 2, the appearances of the go signals induce apparent rotational motions in a clock- or counterclockwise direction. Interestingly, stimulus detections were faster when apparent motions were consistent with the manual object rotation. Motion perception was also facilitated when detections had to be indicated with a foot response (Experiment 3). In sum, we present evidence for motor-visual priming of prepared object manipulations on the perception of visual motions, which suggests a close link between motor and perceptual representations that goes beyond visuomotor associations between object properties and afforded actions.

2.1 Introduction

Recent behavioral and neuropsychological research suggests a close and bidirectional link between perceptual and motor processes (see e.g., Hommel, Müsseler, Aschersleben, & Prinz, 2001). 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). More recent studies 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 visual attention 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).

Interestingly, 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; Craighero, Bello, Fadiga, & Rizzolatti, 2002; Fagioli, Hommel, & Schubotz, 2007). Yet, 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 had been presented. Craighero et al. (1999) observed faster response if the go signals afforded the same type of grasping response as the concurrently 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 (e.g. by a foot response). These results suggest that the preparation of a grasping movement facilitates the visual processing of stimuli sharing the same intrinsic properties and supports the notion of motor-visual priming.

The idea of action-induced attentional effects has received further support from studies that compared grasping and pointing movements (Bekkering & Neggers, 2002; Hannus, Cornelissen, Lindemann, & Bekkering, 2005; Fagioli et al., 2007; Fischer & Hoellen, 2004). For example, it is has been shown that the intention to grasp an object selectively enhances the processing of
object properties such as size (Fagioli et al., 2005) and orientation (Bekkering & Neggers, 2002; Hannus et al., 2005), which indicates that the planning of an action automatically modulates visual attention toward those object dimensions that are relevant for the selection and programming of that particular motor response.

In sum, most of the studies that investigated motor-visual priming effects either examined rather simple actions and focused on the perception of object features, which are associated with a particular kind of hand posture and which are required in each visuomotor transformation for grasping. However, in everyday life, we reach out and grasp an object in order to use it for a specific purpose. For instance, depending on whether we wish to open or close a faucet we grasp it with the intention to rotate it afterwards clockwise or counterclockwise. In other words, almost all our grasping movements are instrumental and directed toward an action goal\(^1\), which involves a certain manipulation of the grasped object. Although it is widely recognized that the planning of grasping actions strongly relies on the visual information we receive about the spatial characteristics of the target object (for review see, e.g., Castiello, 2005) recent research in the field of motor control demonstrates that an intended object manipulation plays a crucial role in the selection of an initial reach-to-grasp movement (see e.g., Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001). Empirical support for this view was derived from the observation that most subjects grasped an object they intend to manipulate in a way that allowed them to finish their action with a comfortable end state even if this implied having to adopt an awkward initial grip (the so-called end-state comfort effect; see e.g., Rosenbaum, Marchak, Barnes, Vaughan, Slotta, & Jorgensen, 1990; Weigelt, Kunde, & Prinz, 2006). However, until now, the relevance of the desired manipulation and the role of action goals have been largely neglected in research investigating the interaction between attentional and motor processes in grasping.

Given that grasping actions are goal-directed and generally guided by the intention to use, displace or control the grasped object, the present study aimed to investigate the nature of motor-visual priming in the context of object-manipulations. Because such a motor action always implies a visually perceivable movement and taking into account the importance of visual feedback for the control of manual actions (cf. Glover, 2004), it is plausible to assume that especially the domain of visual motion perception is characterized by a close coupling of action planning and perception. Surprisingly, however, as yet

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\(^1\)We use the term \textit{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, e.g. from proximal goals like \textit{grasping the faucet} to more distal goals like \textit{filling the bathtub with water} or \textit{having a bath}. In this respect, action goals are here understood as proximal goals at the level of motor intentions (cf. Jacob & Jeannerod, 2005).
little is know about the interference between action and visual 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 observed motions (Michaels, 1988; Proctor, Van Zandt, Lu, & Weeks, 1993; Bosbach, Prinz, & Kerzel, 2004). Nevertheless, the only indication so far for an effect of the reversed directionality, i.e., an impact of action planning on motion perception, is coming from the finding of action-induced motion biases reported by Wohlschläger (2000). In his study, participants had to indicate the direction of ambiguous rotational motion displays while they were turning a knob either clock- or counterclockwise. Wohlschläger (2000) observed that participants tend to judge the ambiguous motions in the rotational direction of their current action and interpreted this as evidence that visual motion perception is biased by actions. Thus, the finding of judgment biases provides some first indications that action planning may indeed facilitate the perceptual processing of visual motion.

Based on these preliminary findings we conducted three experiments to test our hypothesis that a prepared object manipulation would modulate visual attention and particularly facilitates the perceptual processing of visual motion in line with the intended action. In Experiment 1 we established a paradigm to investigate motor-visual priming effects of object manipulations. Experiment 2 further investigated this effect and tested whether action planning has an impact on the perception of visual motions. Experiment 3 was conducted to exclude the possibility that our findings reflect a facilitated action initiation and rather represent an action-induced effect on motion perception.

### 2.2 Experiment 1

The aim of our first experiment was to study motor-visual priming effects in the domain of object manipulation. To this end, we compared the priming effects of two actions. Following the delayed-response paradigm proposed by Craighero et al. (1999), we asked participants to prepare themselves to reach out and grasp an object (object grasping) but added a second action condition in which participants were additionally required to subsequently rotate the object in a given direction (object manipulation). However, in both conditions response execution had to be delayed until the appearance of a visual go signal. The go signal was either a solid circle (neutral stimulus) or a tilted bar that afforded the same type of grip as the prepared action involved (grip-consistent stimulus) or an orthogonal grip (grip-inconsistent stimulus). For both action conditions we predicted a motor-visual priming effect, i.e., faster responses toward grip-consistent stimuli as compared to neutral stimuli.
We assumed that the process of planning to grasp an object in order to manipulate it afterwards is strongly influenced by the purpose of the movement, e.g. the required end position of the object (see e.g., Rosenbaum et al., 2001). Assuming that the goal of an action already affects the process of motor preparation in its earliest stages, we hypothesized that the reach-to-grasp movements prepared for different purposes (i.e., merely holding the object or rotating the object) would affect visual attention differently. Hence, for the present experiment we predict faster detections of grip-consistent stimuli in both action conditions. Since we assume that in the manipulation condition the grasping and rotation of the object is considered and prepared while the initial reach-to-grasp movement is being planned, in this condition we additionally expected to find a facilitated processing of visual features corresponding to the end state of the object rotation.

2.2.1 Method

Participants

Twenty-eight students from the Radboud University Nijmegen participated in the experiment in return 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 and Stimuli

Participants were required to perform grasping movements toward an X-shaped object (manipulandum; see Figure 2.1B) consisting of two perpendicularly intersecting wooden bars (8 by 1.1 by 5 cm each) mounted on a base plate (30 by 15 cm). The manipulandum could be rotated around its crossing point with the rotation axis being parallel to the Cartesian $y$-axis. Owing to small pegs underneath the manipulandum and holes inside the base plate, it clicked into place after rotating it for a multiple of 90°. This mechanism enabled us to keep the orientation of the manipulandum at the beginning of each trial constant even when participants were required to rotate the object. 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 (see below). The manipulandum, which was oriented such that the crossing bars were aligned 45° diagonally to the subject’s midsagittal plane, was positioned behind a wooden screen (height: 44 cm, width: 45 cm) allowing the participants to reach it comfortably with their right hand but obscuring it and their hand from view (see Figure 2.1A).

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, allowing
2.2 Experiment 1

Figure 2.1: 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 $R$. C: Visual stimuli that served as go signals in all three experiments.

them an unobstructed view of the monitor. The Dutch words LINKS (left) and RECHTS (right) served as action cues to indicate the required motor response (a left or a right grasp) in a particular trial. Black bars (subtending a visual angle of $4.1^\circ$ by $1.3^\circ$) tilted from the vertical for either $-45^\circ$ or $+45^\circ$ or a solid circle (visual angle of $2.7^\circ$) served as go signals (see Figure 2.1C). Thus, depending on the required motor response, a go signal could afford the same type of grip as currently prepared action involved (grip-consistent) or it could afford the orthogonal grip (grip-inconsistent). The solid circle, which did not afford any specific type of grip, served as neutral go signal.

Procedure

Participants were randomly assigned to one of two action conditions. Participants in the condition ‘object grasping’ had to grasp the object and hold it for a second without lifting it before returning the hand to the starting position. Participants in the condition ‘object manipulation’, however, were additionally required to rotate the object $90^\circ$, either clockwise (CW) or counterclockwise (CCW). In both conditions the manipulandum had to be grasped along one of its two crossing bars: either with the index finger at the top-left and thumb at the bottom-right leg (called left grasp) or with the index finger at the top-right and thumb at the bottom-left leg (right grasp). In the manipulation condition a left grip needed to be followed by a CW rotation and a right grip by a CCW rotation.

Prior to the actual experiment participants performed two short pre-experimental blocks. In the first block participants were required to reach out and simulate to grasp different bars, presented at different location on the computer screen. The bars were oriented $-45^\circ$ or $+45^\circ$ similar to the go signals in the experimental block and had always to be grasped with thumb and index finger to be placed at the bars’ ends. With this block, we ensured that all participants
associated with each bar orientation the same particular type of grip. In the second block, participants practiced grasping and rotating the manipulandum in the way described above. When the responses were carried out incorrectly, the experimenter corrected the participants and again demonstrated the correct action. Only when participants were able to carry out the movements fluently without vision was the experimental block started.

At the beginning of each trial the participants fixated their eyes on a gray cross presented on the monitor and positioned their hand in the starting position by placing their index finger and thumb around the start peg after which the cross disappeared and the action cues were presented for 2,000 ms. At this point the participants prepared the required action but needed to withhold its initiation. After a random interval between 250 ms and 750 ms the go signal appeared and remained visible for 1,000 ms. After appearance of the go signal participants’ had to initiate their prepared motor response as soon as possible. After holding or rotating the manipulandum they returned their hands to the starting position.

**Design**

Apart from 10 randomly determined practice trials at the beginning, 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, right grasp) and the three types of go signals (circle, bar tilted -45°, bar tilted +45°). Depending on the prepared response, each go signal could be considered as grip-consistent, grip-inconsistent or neutral. Additionally, the experimental design contained the between subject factor Action Condition (object grasping, object manipulation).

**Data acquisition and analysis**

To record the hand movements we used an electromagnetic position tracking system (miniBIRD 800™, Ascension Technology Corporation). Three sensors were attached to the thumb, index finger, and wrist of the participant’s right hand. The hand movements were recorded with a sampling rate of 100 Hz and analyzed off-line. We applied a fourth-order Butterworth lowpass filter with a cut-off frequency of 10 Hz on the raw data. The onset of a reach-to-grasp movement was defined as the moment when the tangential velocity of the index-finger sensor first exceeded a threshold of 10 cm/s. For the movement offsets we used the reversed criteria, i.e. the time when the tangential velocity first dropped below this threshold. For both experimental conditions we computed the mean reaction times (RT; i.e., mean time elapsed between the appearance of the go signal and the onset of the ensuing reach-to-grasp movement).
2.2 Experiment 1

Table 2.1: Mean Reaction Times (in ms) in Experiment 1. The Values in Parentheses Represent Standard Errors.

<table>
<thead>
<tr>
<th>Object Grasping</th>
<th>Object Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GC</td>
</tr>
<tr>
<td>Grasping “Left”</td>
<td>336 (17)</td>
</tr>
<tr>
<td>Grasping “Right”</td>
<td>323 (15)</td>
</tr>
<tr>
<td>Mean</td>
<td>330 (16)</td>
</tr>
</tbody>
</table>

Note. GC = grip consistent; GI = grip inconsistent; N = neutral.

In all experiments reported in this chapter, anticipation responses (response ahead of onset of the go signal 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) were considered errors and excluded from the statistical analyses. A type-I error rate of $\alpha = .05$ was used in all statistical tests. Whenever appropriate, pairwise post-hoc comparisons were conducted using the Bonferroni procedure.

2.2.2 Results

Anticipations occurred in 10.4% of all trials (6.1% concerned responses ahead of the go signal and 4.3% RTs <150 ms). The rate of missing (< 1%) and incorrect responses (2.5%) was low reflecting that the participants had carefully complied with the instructions concerning planning and execution of the required responses.

We applied a repeated measures multivariate analysis of variance (MANOVA)$^2$ with the within-subject factors Manual Response (left grasp, right grasp) and Grip Consistency of the go signal (consistent, inconsistent, neutral) and the between-subject factor Action Condition (object grasping, object manipulation) on the RT data (see Table 2.1). The analysis revealed a simple main effect for the factor Manual Response indicating faster initiations of right grasps (350 ms) than of left grasps (360 ms), $F(1, 26) = 3.57, p < .05$. Apparently, right grasps were easier to perform as this is the natural manner to reach out for the manipulandum with the right hand. Importantly, the main effect of Grip Consistency was significant, $F(2, 25) = 9.95, p < .001$. As anticipated, the response latencies to grip-consistent stimuli (346 ms) were shorter than those to grip-inconsistent (354 ms), $t(27) = -2.28, p < .05$ and neutral stimuli (362 ms), $t(27) = -4.57, p < .001$. The main effect for Action Condition, $F(1, 26) = 2.39, p = .13$, and the interaction of Action Condition and Grip Consistency, $F(1, 25) = 1.79, p = .18$, did not reach significance.

$^2$We used the multivariate $F$-test based on the Pillai-Bartlett $V$ criterion for all within-subject factor analyses reported here (cf. O’Brien & Kaiser, 1985).
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**Figure 2.2:** Mean effects in the response latencies of Experiment 1 as a function of the factors Action Condition and Grip Consistency. Effects are defined as the deviation from the participant’s mean RT in the neutral condition. Error bars represent standard errors.

To examine the grip consistency effects in more detail, we calculated for each subject in the two action conditions the deviation of the mean RT to grip-consistent and inconsistent stimuli from the mean RT to neutral circles. The resulting RT effects are depicted in Figure 2.2 and tested with one-sample t-tests for reliability. As expected, in the object grasping condition action preparation resulted in a significant facilitory effect on the detections of a grip-consistent stimuli, \( t(13) = 2.96, p < .05 \), and did not affect the detections of grip-inconsistent stimuli, \( |t(13)| > 1 \). Interestingly, however, the pattern of effects in the object manipulation condition was different. When intending to manipulate the object not only grip-consistent, \( t(13) = 3.45, p < .01 \), but also grip-inconsistent stimuli—which are here consistent with the end state of the manipulation—were processed faster, \( t(13) = 2.16, p < .05 \).

**2.2.3 Discussion**

Taken together, the perceptual processing of visual bars was facilitated (as compared to neutral solid circle) when participants prepared an action that involved the same type of grip as afforded by the go signal. Hence, a motor-visual priming effect for grip-consistent stimuli was present in both the object grasping and the object manipulation condition. Interestingly, however, besides the finding of priming induced by prepared object manipulations, Experiment 1 also revealed differences in the effect patterns of the two conditions. Whereas, in the object grasping condition the detection times for bars in a grip-inconsistent orientation did not differ from the detection times for neural circles, in the object manipulation conditions RTs showed faster processing of bars in both grip-consistent and inconsistent orientations relative to neutral circles. For an adequate interpretation of these results it is important to note that grip-inconsistent stimuli in the manipulation condition were always consistent with the hand posture after having rotated the object by 90°, or, in other words, grip-inconsistent stimuli were always consistent with the end state of the required object manipulation.
We therefore conclude that the faster responses in the manipulation condition reflect an impact of the prepared object manipulation and indicate a facilitated processing of visual features consistent with the required action end states.

Taken together, the dissociation of RT effects between the two action conditions of Experiment 1 suggest that the participants prepared the manual rotation of the manipulandum in advance and provides a first indication that motor-visual priming effects are not restricted to the processes of visuomotor transformation required for the grip selection and is influenced the intended object manipulation. However, since this interpretation is based on multiple t-tests of the effects in the two action conditions and because of the weak statistical interaction between the factors Action Condition and Grip Consistency in the MANOVA, additional empirical evidence is clearly warranted. Thus, to test our hypothesis that motor-visual priming depends on the intended object manipulation we performed a second experiment, which is detailed next.

2.3 Experiment 2

Experiment 1 had yielded faster responses to stimuli affording the same type of grip as the currently prepared action and hence suggested that motor-visual priming effects not only depend on the selection of the initial grip but are also influenced by the end state of the intended movement. With our second experiment we aimed to test the idea that motor-visual priming indeed goes beyond visuomotor associations between intrinsic object properties and afforded grip. Given that the most basic function of any manual action is to cause changes in our physical world and that the use of an object generally involves an object displacement, the visual perception of motions should be sensitive to the planning of manual object-directed actions. Thus, when people intend to rotate an object and prepare the manipulation in advance this should result in a motor-visual priming of motions related to the intended object displacement.

In Experiment 2 we again used the object manipulation of Experiment 1 but made a crucial modification: before the go signal appeared participants were presented with a stimulus either consisting of a horizontal or a vertical bar. Due to that initial stimulus, the go signal could induce an apparent 45° CW or CWW rotation (see Figure 2.3). 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.
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Initial bar

Clockwise rotation

Figure 2.3: Apparent visual motions caused by the sequence of stimuli in Experiment 2 and 3. Depending on the orientation of initial bar (i.e., horizontal or vertical) the appearance of the go signal (i.e., -45° or +45° tiled bar) induced an apparent rotational motion in a clock- or counterclockwise direction. The neutral condition, in which the go signal (i.e., a solid circle) did not induce an apparent motion, is not depicted in this figure.

2.3.1 Method

Participants

Thirty students from the Radboud University Nijmegen participated in exchange for 4.50 Euros or course credits. All had normal or corrected-to-normal vision and were naive to the purpose of the experiment.

Apparatus and stimuli

The apparatus was the same as in Experiment 1. Also the go signals were unchanged. In contrast to Experiment 1, in all trials an initial stimulus consisting of either a horizontal or vertical bar was presented in the center of the screen that remained visible until the go signal appeared. The initial stimulus had the same size and was presented at the same location as go signals. Note that the go signals were identical to the ones used in Experiment 1. However, due to the presence of an initial bar the appearance of a go signal could induce an apparent rotational motion (see Figure 2.3 for an illustration). For example, the presentation of a +45° tiled bar resulted in apparent CW motion if initial stimulus was oriented vertically and in a CCW motion of it was oriented horizontally. When the circle served as go signal, there was no apparent motion (no rotation). Additionally, we didn’t cue the action preparation by words, as we did in Experiment 1, because the appearance of a word stimulus would have masked the initial stimulus strongly. Instead, now we presented as action cue a small blue or yellow cross (0.9° of visual angle) on top of the vertical or horizontal bar.

Procedure and design

The procedure was basically the same as in Experiment 1, including the pre-experimental and practice blocks. Participants were instructed to always grasp...
Table 2.2: Mean Reaction Times (in ms) in Experiments 2 and 3. The Values in Parentheses Represent Standard Errors.

<table>
<thead>
<tr>
<th>Manual Response</th>
<th>Vertical Initial Bar</th>
<th>Horizontal Initial Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RC (21)</td>
<td>RI (24)</td>
</tr>
<tr>
<td>Left-CW</td>
<td>324 (21)</td>
<td>354 (24)</td>
</tr>
<tr>
<td>Right-CCW</td>
<td>337 (21)</td>
<td>339 (23)</td>
</tr>
<tr>
<td>Mean</td>
<td>331 (21)</td>
<td>347 (23)</td>
</tr>
</tbody>
</table>

Experiment 3

<table>
<thead>
<tr>
<th>Manual Response</th>
<th>Vertical Initial Bar</th>
<th>Horizontal Initial Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RC (17)</td>
<td>RI (15)</td>
</tr>
<tr>
<td>Left-CW</td>
<td>328 (17)</td>
<td>341 (15)</td>
</tr>
<tr>
<td>Right-CCW</td>
<td>326 (16)</td>
<td>334 (19)</td>
</tr>
<tr>
<td>Mean</td>
<td>327 (16)</td>
<td>338 (17)</td>
</tr>
</tbody>
</table>

Note. RC = rotation consistent; RI = rotation inconsistent; NR = no rotation; Left-CW = grasping “left” & turning clockwise; Right-CCW = grasping “right” & turning counterclockwise.

and rotate the manipulandum. Half of the participants were presented with the horizontal and the other half with the vertical bar as initial stimulus. Each trial began with the presentation of a gray cross projected on top of the initial stimulus. As soon as the participants had placed their hand in the starting position, the color of the cross changed to cue the preparation of the object manipulation (remaining visible for 2,000 ms). Blue indicated a left grasp (the index finger at the top-left and the thumb at the bottom-right leg of the manipulandum) and a 90° CW rotation, whereas yellow prescribed a right grasp (index finger at the top-right and thumb at the bottom-left leg) and a 90° CCW rotation. After a random interval (250-750 ms) the initial stimulus disappeared and the go signal was presented for the duration of 1,000 ms.

The experimental block again comprised 144 trials consisting of all possible combinations of the two manual response (left grasp/CW rotation, right grasp/CCW rotation) and the three types of go signals (circle, bar tilted -45°, bar tilted +45°). The orientation of the initial bar (horizontal, vertical) was balanced between subjects. Depending on the induced apparent rotation, the go signals were either consistent or inconsistent with the prepared object rotation.

Data acquisition and analysis

Data acquisition and analysis were identical to Experiment 1.

2.3.2 Results

As in Experiment 1, participants had the tendency to anticipate the go signals (14.9% anticipations; 4.9% of RTs<0 ms and 10.4% of RTs<150 ms). 8.4% of
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**Figure 2.4:** Mean effects (i.e., deviations from the neutral condition) in the response latencies of Experiment 2 as a function of the factors Rotation Consistency and Grip Consistency. Error bars represent standard errors.

the actions were performed incorrectly (i.e., no response or wrong grip or wrong object rotation).

A three-way MANOVA was performed on the mean RTs with the within-subject factors Manual Response (left grasp/CW rotation, right grasp/CCW rotation) and Rotation Consistency (consistent, inconsistent, neutral) and one between-subject factor Initial Bar Orientation (horizontal, vertical). The mean RTs are shown in Table 2.2. As hypothesized, there was a simple main effect for Rotation Consistency, $F(2, 27) = 9.75, p < .001$. All other effects failed to reach significance. Post-hoc $t$-tests yielded shorter RTs to go signals that were consistent with the rotational direction of the action (322 ms) than inconsistent (345 ms), $t(29) = -4.16, p < .001$, or neutral signals (338 ms), $t(29) = -3.31, p < .01$.

Since the go signals were identical to the ones used in Experiment 1, they could also be regarded as consistent, inconsistent or neutral with respect to the required grip. To be precise, with the horizontal bar all rotation-consistent stimuli were simultaneously consistent with the required grip, whereas with the vertical bar grip and rotation consistencies were opposed. A separate MANOVA with the factor Grip Consistency was performed and did not yield any effects in the mean RTs toward grip-consistent (327 ms), grip-inconsistent (326 ms) and neutral go signals (329 ms), $F(2, 31) = 1.05$.

In order to compare the effects of Rotation and Grip Consistency directly and to see whether the two factors interacted, we analyzed the RT effects further. For each subject we calculated the deviations of the mean RTs to the grip-consistent and grip-inconsistent bars from the mean RTs to the neutral solid circles. 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). Averaged RT effects are depicted in Figure 2.4. As could be expected from the results of the analyses above, the main effect for Rotation Consistency was highly significant, $F(1, 56) = 9.61, p < .003$, whereas there was no effect for Grip Consistency, $F < 1$. This in-
dicates a facilitated detection of stimuli eliciting consistent apparent rotations but, in contrast to Experiment 1, no impact on the detection of grip-consistent stimuli. Interestingly, the two factors did not interact, $F < 1$, showing that the rotation consistency effects were independent from the orientation (i.e., grip affordance) of the go signal.

2.3.3 Discussion

In Experiment 2 responses were speeded up when the appearance of the go signal induced an apparent rotational motion in the same direction as the prepared object manipulation. Intriguingly, the priming effects of grip-consistent stimuli as found for the static stimuli in Experiment 1 had disappeared. Possibly, the apparent motions were more salient, and had therefore a stronger impacted on the detection of the go signals, than a static intrinsic stimulus feature like orientation.

We conclude that the observed perception-action interferences reflect motor-visual priming and indicate a perceptual benefit for consistent visual motions. That is, we interpret our findings as evidence of an impact of action planning on the visual processing of motions. However, since in Experiment 2 the execution of the manual actions was coupled with the motion detections we cannot rule out an alternative explanation in terms of a stimulus-response priming effect. In other words, rather than an action-induced effect on perception, the response latency differences might reflect an accelerated initiation of manual object rotations consistent with the visual motion, i.e., visuomotor priming (cf. Craighero et al., 1998; Vogt et al., 2003) at the level of response execution, which would be an effect of opposite directionality. Thus, we conducted a third experiment to distinguish between these two possible interpretations.

2.4 Experiment 3

With this third experiment we sought to substantiate our assumption that the RT differences in Experiment 2 reflected a motor-visual priming of motion perception rather than stimulus-response priming. Again, participants prepared one of two object manipulations. However, this time the onset of the visual stimulus did not prompt the execution of the grasping response. Instead, participants were asked to signal the motion detections by pressing a foot pedal and to postpone the execution of the prepared object manipulation until the presentation of later in the trial (i.e., following a second auditory go signal).

The rationale of Experiment 3 was as follows: if, as hypothesized, the preparation of a manual response indeed facilitates the perception of consistent motions, we should observe a similar priming effect when the motion detections to be indicated with another effector system, in this case the foot (cf. Craighero et al.,
1999; Fagioli et al., 2007). By contrast, if the alternative explanation holds that in Experiment 2 the perception of motions accelerated the initiation of object manipulations in the same direction, we should not find any effects on the execution of the foot responses, because they were identical in all trials and unrelated to the rotational stimulus motions.

2.4.1 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 and stimuli

The apparatus and stimuli were identical to those used in Experiment 2. 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 to indicate a correct response. However, when participants responded before the onset of the visual go signal they were given negative auditory feedback (4400 Hz lasting 200 ms). The auditory go signal triggered the execution of the prepared manual action and consisted of a 900-Hz tone (150 ms duration).

Procedure and design

Comparable with the previous experiment, the participants were again visually cued to prepare to grasp and rotate the manipulandum. However, in contrast to Experiment 2, they were now required to make a foot response with their right foot as soon as the visual stimulus appeared. The auditory go signal indicating the initiation of the manual action was presented 600 ms after the foot response had been given.

Experiment 3 was divided into four blocks of 48 trials each. In contrast to Experiment 2, the orientation of the initial bar was now 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 was reversed.

Data acquisition and analysis

Data acquisition and analysis were identical to those employed in Experiment 2 with the exception that we used a fourth motion-tracking sensor to measure the
foot responses. We used the same method (i.e., velocity threshold of 10 cm/s) to determine the foot response latencies as for the hand response in Experiment 1 and 2.

### 2.4.2 Results

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

The three-way MANOVA of the foot RTs with the within-subject factors Manual Response (left grasp/CW rotation, right grasp/CCW rotation) and Rotation Consistency (consistent, inconsistent, neutral) and Initial Bar Orientation (horizontal, vertical) revealed a simple main effect for Rotation Consistency, $F(2, 13) = 4.34$, $p < .05$ (see Table 2.2 on page 27). Post-hoc $t$-tests yielded shorter RTs for responses following visual go signals that were consistent with the planned rotation (320 ms) than for inconsistent (332 ms), $t(14) = -3.08$, $p < .01$, and neutral 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, $F(2, 13) = 3.0$, $p = .08$, 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 $< 1.8$).

To compare rotation and grip consistency effects we performed a separate analysis. Like in Experiment 2, we calculated the RT effects of the presentation of the tilted bars (defined as deviations from the RT for the neutral stimulus) per subject for all conditions and entered this data into a two-way MANOVA with the factors Grip Consistency (consistent, inconsistent) and Rotation Consistency (consistent, inconsistent). Again, there was no effect for Grip Consistency, $F(1, 14) < 1$, but a significant effect for Rotation Consistency, $F(1, 14) = 5.46$, $p < .05$, indicating a facilitated perception of consistent rotational motions relative to the neutral, no motion condition, while no differences were found for inconsistent motions.
2 Action and Visual Processing

2.4.3 Discussion

The foot-response latencies of Experiment 3 replicated the effects of Experiment 2, i.e., faster foot responses were made toward stimuli inducing an apparent rotation consistent with the prepared object manipulation. Because the detection of the motions and their signaling took place before the manual action had to be executed, and since the foot responses were unrelated to the visual stimuli, we can exclude the existence of stimulus-response priming at the level of response initiation. Thus, the results of Experiment 3 support the assumption of motor-visual priming: a facilitated perceptual processing of visual motions in the same direction as the intended object manipulation. This shows furthermore that motor-visual priming occurs already after action preparation and even in the absence of the execution of the response.

2.5 General Discussion

The results of the present study indicate that action planning has an impact on the perceptual processing of visual motions. Experiment 1 showed action-related effects of object manipulation on visual perception. Whereas in the object grasping condition only a grip-consistency effect was found, we observed in the object manipulation condition a grip-consistency effects as well as a facilitated processing of stimuli consistent with the end state of the required object manipulation. The data demonstrated that the preparation to manipulate an object facilitates the perception of stimuli that afford the same type of grip as the currently prepared action involved. Moreover, it indicated that motor-visual priming might not be restricted to the perception of grip-consistent stimuli but could also affect the processing of stimuli related to other states and features of the intended action. Experiment 2 investigated further the nature of motor-visual priming. When the appearance of the visual go signal induced an apparent rotational motion we observed a benefit for the perception of rotation-consistent motions. The effects of grip and end-state consistency disappeared. Importantly, the same effects on motion perception were also present in Experiment 3 in which the manual response was unrelated to the motion detection and participants indicated the detection of the visual stimuli by pressing a foot pedal. This finding clearly rejects the alternative interpretation of stimulus-response priming. In conclusion, the present findings demonstrate that planning an action facilitates the processing of visual motions if they are consistent with the intended action. The observed action-induced effects on perception indicate a modulation of visual attention as a result of motor-visual priming and suggest a bidirectional link between motor and perceptual representations that goes beyond the visuomotor association of superficial motor-object characteristics.
As mentioned in the introduction section, we are not the first to demonstrate action-induced effects on visual attention (cf. Craighero et al., 1999; Müsseler & Hommel, 1997; Wohlschläger, 2000; Bekkering & Neggers, 2002; Hannus et al., 2005; Fagioli et al.; 2007). These earlier studies, however, reported effects for simple motor responses (i.e., key presses or mere grasping actions) on the visual processing of intrinsic object properties (e.g. location or orientation) that are relevant for the programming of an object-directed motor action (e.g. grasping or pointing). The present study extends these findings to the domain of object manipulations. Furthermore, we demonstrate that action planning not only has an impact on the processing of visual object properties but also on the perception of visual motions. Although there is evidence that the perception of motions facilitates the selection of compatible motor responses (cf. Bosbach et al., 2004), to date little was known about the reversed effect. Wohlschläger’s study (2000) gave some indications for an action-induced priming of motion perception by showing that the participants’ direction judgments of ambiguous apparent motion were systematically biased toward the rotational direction of a simultaneously performed turning action. Although it cannot be excluded that the effects in such a paradigm may have been caused by a guessing bias in perceptually unclear situations rather than a perceptual bias, Wohlschläger’s (2000) observations were in line with the idea that the planning and execution of motor actions affect the visual processing of motions. With the present paradigm we excluded the possibility of biases caused by guessing. The observed differences in the detection latencies of apparent motions thus provide new evidence for action-induced effects on motion perception. Furthermore, our experimental design allowed the detection of attentional effects induced by goal-directed actions consisting of more than just a single movement: the data showed a motor-visual priming of motions when participants prepared a more complex motor sequences such as reaching, grasping and manipulating an object. Note that the effects occurring in the onset of the reaching movements were driven by a movement (i.e., the object rotation) that had to be performed later in the motor sequence. This indicates that participants prepared the actual object manipulation before the reach-to-grasp movement was initiated. Consequently, the effects of the object manipulation can be interpreted as evidence for a goal-directed action planning and they stress the impact of action intentions (e.g. rotating the object) on the process of early movement selection (see Jeannerod, 1999). This would underpin the recent model of motion control proposed by Rosenbaum et al. (2001), which states that grip selection depends on the intended object manipulation and is mainly affected by the desired end position of the movement. The relevance of end postures in action planning might then also account for our observation in Experiment 1 that visual detections were facilitated when stimuli were consistent with the end state of the required rotation (i.e., grip inconsistent stimuli).
Craighero et al. (1999) had earlier reported priming effects of prepared reach-to-grasp movements. The present experiment replicates their findings and additionally controls for a potential confounding that made it difficult to interpret their reaction-time differences as action-related effects. In contrast to our study in which we used a single object in a constant orientation, Craighero and colleagues (1999) required participants to grasp bars positioned in different orientations that were each associated with one specific type of grip. The authors observed faster responses when the go signals afforded the same action as the to-be-grasped object. Since the actions were determined by the object orientation, it is unclear whether the stimulus detections interacted with the prepared action or with the representation of the to-be-grasped object. That is, it might be possible that priming effects were fully independent from the concurrent motor intention and were instead driven by an overlap of visual object properties (e.g., object orientation or grip affordances) between the go signal and the object. With the present paradigm, however, we can clearly reject this alternative account because participants had to grasp one object, whose orientation remained stable, in two different ways. That is, the same manipulandum was always associated with both grasping responses. Consequently, the grip-consistent effects in Experiment 1 were not triggered by the to-be-grasped object but emanated from the prepared action. This interpretation received additional empirical support from our findings of visual motion priming in Experiments 2 and 3, which indicated the presence of an impact of the intended rotation and ruled out the possibility of a consistency effect between the object and go signal.

A facilitatory motor-visual priming effect seems to conflict with studies that reported an impaired accuracy in the identification of stimuli that shared features with a prepared action (the so called action-effect blindness; Müseler & Hommel, 1997; Wühr & Müseler, 2001; Kunde & Wühr, 2004). For example, Müseler 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., if a left-pointing arrowhead appeared while planning a left keypress). A crucial difference between the findings of motor-visual priming and action-effect blindness is that the former effect represents a reaction-time effect 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 disparate perceptual effects (Santee & Egeth, 1982), we argue that also from a theoretical point of view the two findings are not in contradiction. The impaired accuracy in the perception of action-consistent stimuli has mostly been explained within a common coding framework (cf. Theory of Event Coding; Hommel et al., 2001), which suggests that perception and action planning use shared codes that can represent the features of both perceived stimuli and prepared actions (see e.g., Wühr & Müseler, 2001). Accordingly, the
preparation of an action and its maintenance in memory results in an integration of all required 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 required for the representation of a perceptual event. However, 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, 2004). Thus, 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 processing of events sharing these features. Consequently, the planning of an action and the resulting integration of feature codes should only cause inhibitory effects on the attempt to integrate this code in a second representation. It is important to discern that in our paradigm the direction of the motion was irrelevant to the participants’ task and no short-term memory representation of the perceptual event had to be created for later recall. We therefore did not expect action-effect blindness 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 cognitive representation is impaired, as predicted by the Theory of Event Coding (Hommel et al., 2001), can not be answered at this point and requests additional investigations of action effects on the accuracy of motion perception.

As recently argued by Fagiolli et al. (2007), actions cannot only affect visual attention in terms of feature-based interferences but also in terms of a bias towards an entire stimulus dimension, which results in a facilitated processing of all features defined in this dimension. This notion is supported by studies that compared the impact of grasping and pointing actions on the ability to detect a target object among distractors (Bekkering & Neggers, 2002; Hannus et al., 2005) or to identify deviants in sequences of visual events (Fagiolli et al., 2005). With these paradigms it could be shown that the intention to grasp selectively enhances the visual discrimination of the grasp-relevant dimensions size and orientation. Noteworthy, from research on object perception we know that it is exactly these two stimulus dimensions that are directly associated with specific types of motor responses (Ellis & Tucker, 2000; Tucker & Ellis, 1998). For example, Ellis and Tucker (2000) demonstrated that the perception of big and small objects automatically potentiates the related grasping action, that is, either a response with the whole hand (power grip) or with the thumb and index finger only (precision grip). Apparently, effects of object affordances on response execution reflect the same close bidirectional link between object and action representation as the effects of action planning on object perception described above.

Taken together, previous studies on the interference between grasping actions and perception—including the work of Craighero et al. (1999)—focused on the two perceptual dimensions size and orientation, both crucial for the visuomotor
transformation process and thus for the selection and programming of reach-to-grasp movements. The current study demonstrates an action-induced effect that cannot be explained by the visuomotor association between intrinsic object properties and selected grip. Rather, we argue that the visual motion priming originates from the relation between the action goal (i.e., the object manipulation) and the expected visual-action effects (i.e., a rotational motion). We base our interpretation on the concept of ideomotor action (cf. Greenwald, 1970a; Stock & Stock, 2004), which basically holds that actions are represented and planned in terms of their sensory outcome. Action planning is accordingly understood as a goal-driven process that involves an anticipation of the desired action effects at a sensory level. Since motor preparation is accompanied by an activation of sensory information, it can be predicted that motor preparation affects visual processing. In line with this reasoning, we interpret our results as an enhanced processing of events that are consistent with the expected action outcome. In sum, the motor-visual priming of motion perception supports the idea that action planning involves an anticipation of sensory consequences and furthermore suggests that attention is modulated toward changes in the environment that represent the potential consequences of the intended action.
Chapter 3

Action and Semantic Processing

Semantic Activation in Action Planning