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Perceptuomotor rules as prediction tools in (joint) action: The case of orientation perception

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A B S T R A C T

The human action system has a layered structure supporting a cascade of partially overlapping information processes in multiple, interlinked representational spaces. Apart from the mirror neuron system which through motor resonance mediates one's understanding of the action goals of one's partner, perceptuomotor rules like Fitts' law, the Isogony Principle, and sequencing heuristics provide further sources of prediction in (joint) action. The present study focuses on a perceptuomotor rule that describes how the orientation of framed, tilted objects is perceived and acted upon by individuals. In two experiments involving the Rod-and-Frame Illusion (RFI) participants were asked to perform delayed responses that consisted either of (1) making a perceptual judgment in a forced-choice paradigm, or (2) rotating and propelling a hand-held cylinder. Irrespective of response type, the effects of the RFI proved robust and constant. The relevance of the findings for prediction in joint-action tasks is discussed.

1. Introduction

The human action system is hierarchically organized and supports both serial and parallel information processes in multiple, interlinked representational spaces (see Fig. 1; Van Galen, Meulenbroek, & Hylkema, 1986). To compensate for sensorimotor delays and to anticipate the perceptual consequences of planned action in individual task performance, the system makes use of forward models (Kawato, Furawaka, & Suzuki, 1987; Wolpert, Doya, & Kawato, 2003).

During action observation the mirror-neuron system mediates motor-resonance driven anticipatory processes. Also, the motor behavior of the person observed might signal regularities that help predict and anticipate the observed person's behavior (Cuijpers, Van Schie, Koppen, Erlhagen, & Bekkering, 2006; Sebanz & Knoblich, 2009). For example, at a dinner table, observing a person move his hand into a particular direction, one can easily (seemingly automatically) infer which object on the table he will pick up. If the hand happens to decelerate substantially and its speed drops below a critical threshold, one will probably expect an upcoming *careful* interaction with the to-be-grasped object. If, however, the speed of the approaching hand remains high or diminishes only slowly, one may expect the object to be hit or squashed rather than carefully being picked up. Clearly, the example just described capitalizes on the general relationship between speed and accuracy in biological motion, also discernible in motion perception (Grosjean, Shiffrar, & Knoblich, 2007).

Indeed, if perceptuomotor rules have similar characteristics in perception and in action, they may serve as a reliable basis for prediction basis in shared task performance whether or not they are represented internally by means of a common code (Franz, 2001; Sebanz & Knoblich, 2009). Furthermore, perceptuomotor rules operate at different time scales to which their prediction windows correspond. Whereas at lower processing levels of the cognitive system anticipation intervals may not exceed 100 ms, at higher levels prediction intervals may sometimes span several

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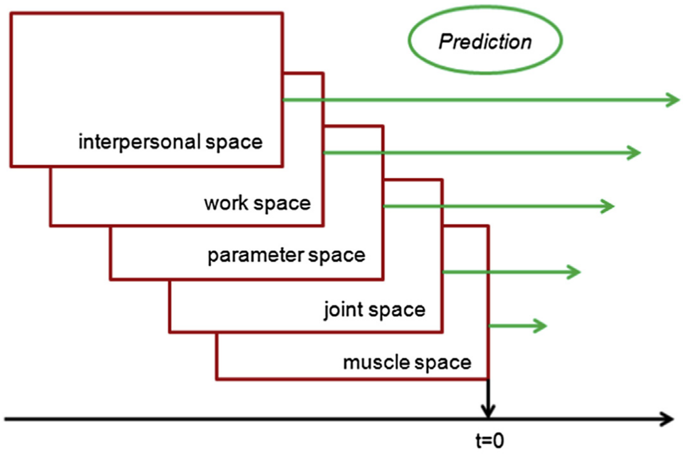

Fig. 1. A cascade of representational spaces in action control. Prediction windows are depicted by the horizontal arrows. Arrow size represents prediction extent.

seconds or even minutes (cf. Tanida & Pöppel, 2006). The different prediction intervals are illustrated by the horizontal arrows passing to the right of $t = 0$ in Fig. 1, where arrow length represents extent of prediction.

Motor resonance thus can work as a joint action "tool." It is supplemented by intuitive rules of perceptuomotor behavior, similar to the rules that shape intuitive physics. Instead of multiple observations of phenomena that obey physical laws, they are the long-term effects of observing other people's behavior that obeys perceptuomotor rules (for a comparison of intuitive physics and intuitive psychology, see Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001).

Given the multiple information processes involved in the preparation of purposeful action, one may wonder which regularities in performance might form a basis for prediction in joint action. Processes in muscle space are hardly visually observable, and therefore probably of little use for shared task performance. Regularities at higher levels, however, are all clearly visually discernible and thus potentially informative for future shared action. Postural changes that are planned in joint space, for example, may reveal the expected weight of to-be-grasped objects (cf. Grèzes, Frith, & Passingham, 2004; Meulenbroek, Bosga, Hulstijn, & Miedl, 2007). While trunk and proximal arm-segment involvement when approaching objects may cue future lifting of a heavy object, distal arm and hand rotations in the same context suggest that a lightweight object will be manipulated.

The end-state comfort effect (Meulenbroek, Thomassen, Schillings, & Rosenbaum, 1996; Rosenbaum & Jorgensen, 1992) is another perceptuomotor rule that affords prediction. People tend to pick up objects in awkward postures to ensure they end up comfortably. In parameter space, the predictive power of the speed-accuracy trade-off for reaching movements, as formally captured by Fitts' law (Fitts, 1954), has been illustrated above. Similarly, the Two-Thirds Power Law (Viviani & Terzuolo, 1982), which relates instantaneous path curvature to movement speed, both in curvilinear trajectory formation and perception (Kandel, Orliaguet, & Viviani, 2000; Viviani & Stucchi, 1989), provides a solid basis to predict upcoming written text. Another set of perception–action links with predictive power is formed by sequencing heuristics or "grammars of action," as originally described by Bruner (1971) and Restle (1970). Preferences for sequencing actions along specific spatial dimensions (e.g. drawing the individual line segments in a top-to-bottom direction when copying geometrical patterns), or in line with certain principles of economy (using the minimum number of pen-lift movements necessary when copying geometrical patterns), offer exceptionally effective predictions of the order in which subunits of compound action sequences will be generated (see e.g. Smyth, 1989).

In the remainder of this paper we will focus on a specific perceptuomotor rule that affects the perception of the orientation of framed, tilted objects. If the behavioral regularities—or the constant and variable errors—that we observe in this context remain invariant across qualitatively different tasks, the insights we obtain into how people perceive and interact with framed objects may serve as a basis for prediction in joint action tasks (Sebanz & Knoblich, 2009). To test our contention we exploit the Rod-and-Frame Illusion (RFI). This paradigm has been widely used to investigate orientation perception; besides, illusions usually have strong task-dependent effects.

Over the past decade, the neurocognitive basis of perception–action relationships has extensively been studied by exploiting visual illusions. The many studies of this type have employed size-constancy illusions like the Ebbinghaus circles (Aglioti, Desouza, & Goodale, 1995; Fischer, 2001; Franz, Fahle, Bülthoff, & Gegenfurtner, 2001), the Müller-Lyer illusion (Glover, 2004; Heath, Rival, & Binsted, 2004), or the Ponzo illusion (Jackson & Shaw, 2000). Such illusions elicit the erroneous perception of the size of one of the elements in a compound stimulus by manipulating aspects of one or more of the surrounding stimulus elements. In the present study we contribute to this line of research by focusing on the perceptuomotor behavior that results from systematic, context-induced misperceptions of line orientations. The topic is related to the Roelofs effect (e.g Bridgeman, Kirch, & Sperling, 1981), in which a laterally shifted frame induces a misperception of location. Here, instead of location, we focus on the perception of orientation.

Milner and Goodale (1995) proposed a distinction between visual processing for perceptual awareness and visual processing for action, the two visual systems relying on different visual representations (Aglioti et al., 1995; Lee & Lishman, 1975; Milner, 1995; Milner et al., 1991; Servos & Goodale, 1995). The vision-for-action system uses an egocentric, spatially accurate visual representation, whereas the vision-for-perception system uses a more allocentric visual representation that is more vulnerable to effects of contextual stimuli. Milner and Goodale's model predicts that tasks that primarily require perceptual processing should be more susceptible to visual illusions than tasks that mainly rely on motor processing. Before we specify the tasks used in the present study, we first turn to the neural support for the views expressed in Milner and Goodale's model.

Beyond the occipital cortex, visual processing is indeed divided neurologically into two streams directed toward temporal and parietal cortical areas; these are referred to as the ventral and dorsal stream, respectively. The anatomical separation of these areas supports the idea of parallel visual processing, specifically the model of Milner and Goodale (1995). The ventral stream is mainly involved in recognizing visual objects and constructing a consciously accessible representation of the visual scene. The dorsal stream plays a role in visual guidance of body movements and is not accessible to awareness (Milner et al., 1991; Schmidt, 2002). The two streams differ both functionally and temporally. The ventral stream is considered to be involved in processing intrinsic stimulus attributes (Pisella, Arzi, & Rossetti, 1998; Rossetti & Pisella, 2002), has relatively long visual latencies, and acts as a gateway to the memory systems of the brain, which further modulate it (Milner & Goodale, 1995). The dorsal stream is considered to be involved in extrinsic, spatial stimulus attributes, has short visual latencies (Rossetti & Pisella, 2002), and operates in a much more bottom-up fashion, transforming visual information immediately into motor representations that guide our manual, locomotor, and ocular actions (Milner & Goodale, 1995). Importantly, the dorsal and ventral streams are not entirely separated from each other; several anatomical interconnections enable the two streams to interact (Rossetti, Pisella, & Pelisson, 2000).

In contrast to Milner and Goodale (1995), Franz et al. (Franz, 2003; Franz et al., 2001; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000) have argued against a clear dichotomy between perception- and action-related information processing. Rather, they have claimed that vision for perception and vision for action share a common representational basis. More specifically, these authors criticized studies that found differences between perceptual and motor responses for not adequately matching them. If this criticism is valid, one would not expect different effects of visual illusions in perceptual versus motor tasks. To support their claim, Franz et al. refer to studies that have demonstrated size-constancy illusions in both visual and motor tasks (Franz, 2003; Franz et al., 2001; Pavani, Boscagli, Benvenutti, Rabufetti, & Farné, 1999).

Our study of context-sensitivity in the perception of framed, tilted objects is also related to the ongoing debate whether visual illusions differentially affect perceptual and motor tasks, even in adequately matched experiments. Moreover, tasks using perceptual adjustments (Fischer, 2001), forced-choice size comparisons (Aglioti et al., 1995; Glazebrook et al., 2005; Heath et al., 2004; Meegan et al., 2004), manual size-matching (Daprati & Gentilucci, 1997; Franz, 2003), and drawing (Daprati & Gentilucci, 1997) have all consistently been shown to be affected by size-contrast illusions. By contrast, motor responses were affected in some studies (van Donkelaar, 1999; Franz, 2003; Glazebrook et al., 2005; Heath et al., 2004; Meegan et al., 2004) and hardly or not at all in others (Aglioti et al., 1995; Daprati & Gentilucci, 1997; Fischer, 2001).

If Franz et al.'s reasoning is correct, the effects of the Rod-and-Frame-Illusion (RFI) should also remain constant across tasks that differentially tap into perceptual or motor processes. Fig. 2 shows an example of an RFI display. Although the rod is vertically oriented, the tilted frame surrounding it leads to the rod being readily perceived as oriented slightly in the opposite direction.

As mentioned above, dorsal and ventral streams have different latencies, and it has been shown that illusion effects depend on response timing (Westwood & Goodale, 2003). Therefore, in the present study, the timing of the stimulus events was kept under control in the experimental tasks, which varied from more perceptual (Experiment 1) to more motoric (Experiment 2). We decided to study the task-dependency of the RFI in a paradigm with 1000-ms delayed responses and to explore response-duration effects. However, since the latter effects did not reveal additional information on orientation perception and reproduction, we will, for sake of brevity, not report them.

In the first experiment of the present study, participants were briefly shown an RFI-stimulus, followed by a 1000-ms interval. Next, another rod was shown (in half the trials, the orientation differed $+5^\circ$ or -5° from the initial rod orientation). The participants had to judge whether the orientation of that rod was similar to, or different from the initial rod orientation. The second experiment was set up to rely more on motor processes than the first experiment. Now, after the RFI stimulus and a 1000-ms interstimulus interval, participants were asked to move a hand-held cylinder forwards toward the computer screen in order to match its orientation with the orientation of the rod that they had previously seen. In both experiments the initial stimulus was visible for 300 ms.

In sum, we investigated the task-dependency of the RFI and expected, in line with the claims made by Franz et al. (2001), a high degree of similarity between the observed RFI effects in the two tasks under study.

2. Experiment 1

2.1. Method

2.1.1. Participants

Ten right-handed participants, 3 male and 7 female, with ages ranging between 19 and 37 years (mean = 24.6 years; SE = 1.8 years), participated in this experiment for

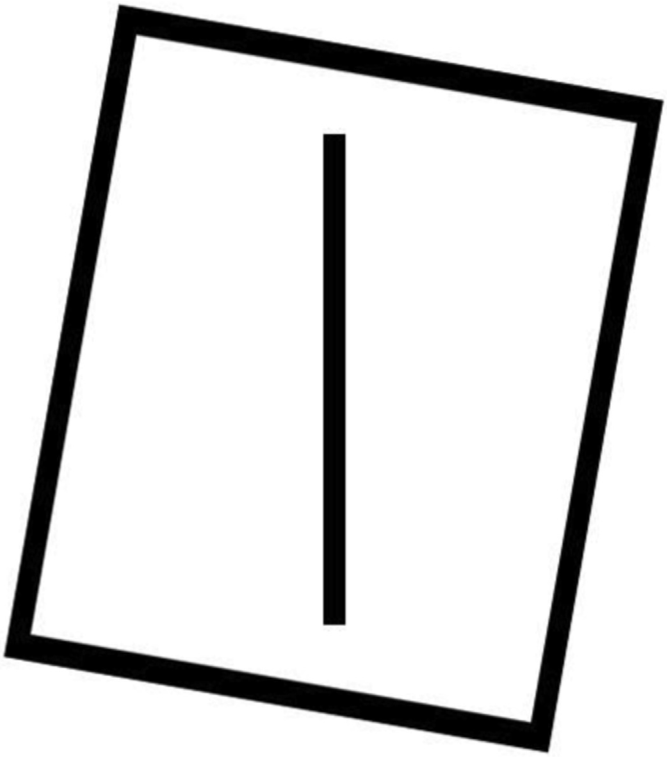

Fig. 2. Example of the Rod-and-Frame Illusion.

remuneration or course credit. All participants were naïve about the goals of the experiment. All had normal or corrected-to-normal vision.

2.1.2. Material and design

The stimulus consisted of a rod (height × width: 111 mm × 8 mm, 4.2° visual angle) that was presented in light gray on a black background at the center of the computer screen. The rod could appear in one of three different orientations (−5°, 0°, and 5°, relative to the gravitational vertical which was labeled 0°). Clockwise (cw) rotations were defined as positive, counterclockwise (ccw) rotations as negative. The frame (height × width: 167 × 131 mm, 6.4° × 2.5° visual angle) could be presented in one of seven different orientations (−15°, −10°, −5° 0°, 5°, 10°, and 15°, rotated from the vertical around the same axis as the rod)—or it was absent. In order to have equal numbers of vertical and tilted rod orientations, the numbers of trials with rod orientations of −5°, 0°, and +5° were in the following proportion: 1:2:1. Overall the design of the experiment consisted of 3 First Rod Orientations (−5°, 0°, +5°) × 8 Frame Conditions (−15°, −10°, −5°, 0°, 5°, 10°, 15°, and no frame) × 2 Second Rod Deviations (0° versus 5°) × 2 Directions of Deviations of Second Rod (cw or ccw) × 8 replications, amounting to 768 trials.

2.1.3. Procedure

Participants sat comfortably in a normal chair with arm rests, at a distance of about 1.5 m from a computer screen. In order to minimize external orientation cues, a circular 100-cm diameter black screen with a circular opening in the center 28 cm diameter was placed in front of the computer monitor. The table on which the monitor stood was covered with black fabric and the room was darkened during the experiment. Trials began with an interstimulus interval (ISI) of 1000 ms, after which the stimulus (RFI display) was displayed for 300 ms, followed by a 1000-ms delay period, during the first 50 ms of which a semi-random mask pattern was shown. A short auditory cue was presented immediately after this delay period. Next, a single line was presented, with an orientation that, on half of the trials, was identical to the orientation of the rod in the RFI display, but on the other of the trials had a different orientation (by +5° or −5°). Participants were asked to judge whether the second rod had the same orientation as the first rod by pressing one of the two buttons on a button box. A schematic overview of the timeline is shown in Fig. 3. Half the participants were instructed to press the right key to indicate a same response, while the other half of the participants were instructed to press the left key to indicate a same response. After receiving written and verbal instructions, participants performed 10 practice trials before completing 4 blocks of 192 trials, with breaks in between. The experiment lasted about 1 h per participant.

2.1.4. Data analyses

Perceiving the RFI illusion depends critically on the (physical) angular difference between the rod and the

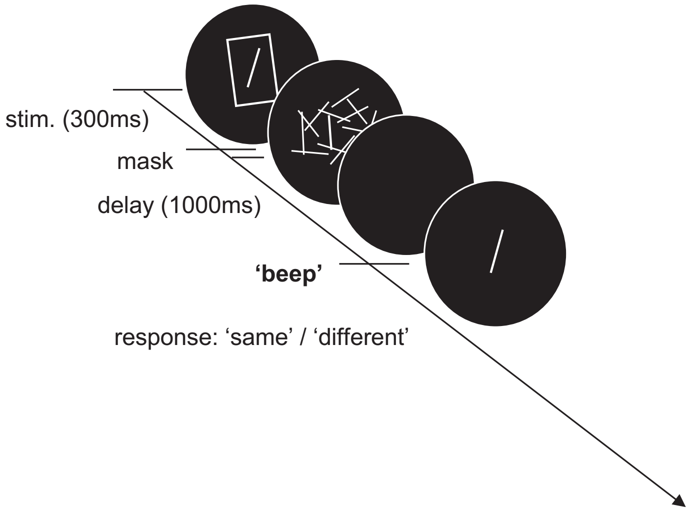

Fig. 3. Trial events in Experiment 1.

frame. To analyze participants' results, the absolute angular difference between the rod and the frame was taken as the main independent variable for all stimuli. Angular difference had five levels (0°, 5°, 10°, 15°, 20°). The dependent variable was participants' performance, expressed as percentage of correct responses. A repeated measures ANOVA was performed with these two variables, using pairwise comparisons to investigate the differences between the levels.

2.2. Results

Trials with reaction times under 300 ms were excluded from the analyses. Based on this criterion, 26 trials (0.34%) had to be excluded. The average percentage of error responses was 22% (SE = 0.5%), indicating that, overall, participants made errors on 22% of the trials. A one-factor repeated measures ANOVA was performed with angular difference (5 levels: 0°, 5°, 10°, 15°, 20°) as the independent variable and performance (or percentage of correct responses) as the dependent variable. The main effect of angular difference was significant [$F(4,6) = 6.68$, $p < .05$]. Pairwise comparisons revealed that the 0° difference between the rod and the frame resulted in significantly better performance compared to the other angular differences (all p's $< .01$). The same was true for the condition with a 5° angular difference (all p's $< .05$). The remaining pairwise comparisons did not show significant differences in percentage of correct responses. Fig. 4 shows the participants' performance as a function of angular difference.

2.3. Discussion

The main effect of angular difference that was found in the experiment illustrates the basic illusion in an RFI display: when a rod is surrounded by a rectangular frame and there is a slight angular difference in orientation between these two elements, a misalignment of the rod may be perceived. Here, this perceptual misalignment was measured in a delayed match-to-sample task and an increasing decline in performance was found with increasing angular difference between the two elements of the RFI displays. It should be noted, however, that the pairwise comparisons revealed that the main effect was due merely to performance in the 0° and 5° conditions, as compared to the other conditions. With an angular difference of 10° and more, perceived misalignment did not increase further in this match-to-sample task. Though it is not the main goal of our study, we predict that a U-shaped curve would be found should angular differences up to 45° be investigated.

This perceptual decision experiment is a necessary first step toward investigating to what extent participants are susceptible to the illusion when a more motoric component is introduced. After the current goal of this study, to investigate a perceptuomotor rule as a basis of prediction in joint action tasks, the logical next step in our exploration is to evaluate whether the RFI also affects task performance should the experimental task contain a more motoric component. To this end, a second experiment will be performed in which participants are asked to reproduce the orientation of a previously perceived line element (i.e., the rod in the RFI display) by rotating a hand-held cylinder.

3. Experiment 2

3.1. Method

3.1.1. Participants

Twelve naïve right-handed people, four men and eight women, with ages ranging between 19 and 31 years (mean = 23.5 years; SE = 1.1 years), participated in the experiment for remuneration or course credit. None of them had participated in the first experiment and all had normal or corrected to normal vision.

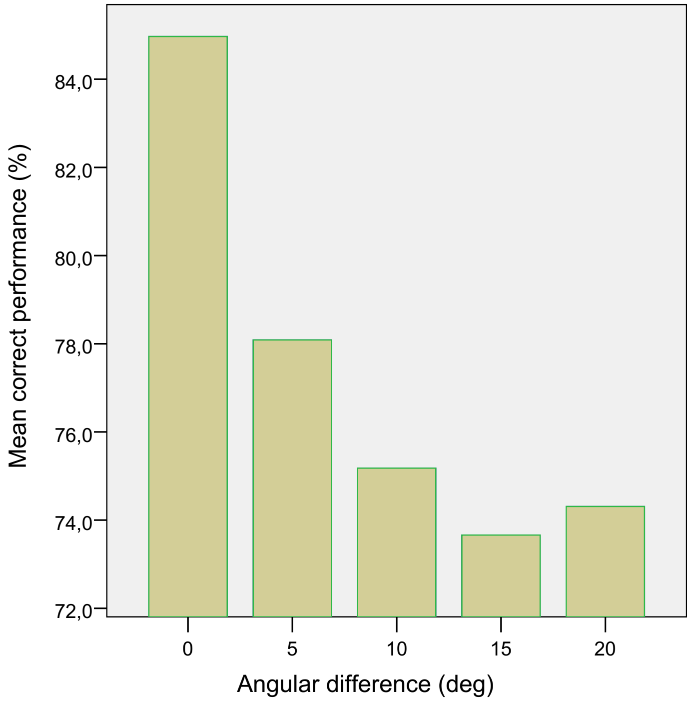

Fig. 4. Experiment 1, graph of mean correct performance for all participants as a function of (absolute) angular difference between rod and frame.

3.1.2. Material and design

The setup was similar to the first experiment. Rod Orientations could be −5°, 0°, or 5° and Frame Conditions could be −15°, −10°, −5°, 0°, 5°, 10°, or 15°—or no frame. As in Experiment 1 there were an equal number of trials with vertical and tilted rod orientations: trials with rod orientations of −5°, 0°, and +5°, were in the proportion 1:2:1. There were 2 Rod Conditions (vertical versus tilted) × 2 Tilted Rod Orientations (−5°, 5°) × 8 Frame Conditions (−15°, −10°, −5°, 0°, 5°, 10°, 15°, no frame) × 2 Start Positions (horizontal versus vertical) × 5 Replications, yielding two blocks of 160 trials. Start Position (horizontal or vertical) was varied between these blocks and was counterbalanced across participants.

Participants responded by moving a hand-held cylinder (diameter: 4 cm, length: 20 cm, weight: 222 g) forward toward the screen, and aligning it with the orientation of the rod that was previously shown. The cylinder was designed so it could radiate white light as soon as the go-signal sounded. In order to prevent reflection images on the monitor that was used to present the stimulus, the side of the cylinder that faced toward the screen was covered with black sticky-foil, leaving a 20 cm × 2.2 cm area open that faced toward the participant. The cylinder was connected by a cable on one end to a computer to register final orientations. To control for a possible difference in the weight distribution of the cylinder, half of the participants held the cylinder with the cable closest to their thumb and half held the cylinder with the cable closest to their little finger.

3.1.3. Procedure

Participants sat in a chair, holding the cylinder in their right hand with a power grip while their arm rested comfortably on the armrest. They were instructed to hold the cylinder in a horizontal or vertical start position between responses. Stimuli were shown for 300 ms, followed by a 1000-ms interval, during the first 50 ms of which a semi-random mask pattern was shown. Participants were asked, after hearing the go-signal, to make a smooth forward movement by stretching their right arm toward the screen while rotating the cylinder into the same orientation as the rod they had previously seen, and to keep the cylinder in that position until, after 2 s had elapsed, another tone indicated the end of the trial. Participants were then instructed to assume the starting position again and wait for the next trial. After getting written and verbal instructions, participants performed at least 15 practice trials. They were allowed to take a brief pause in between trials, when needed. There was a longer break between the two blocks of trials, and the whole experiment lasted about 80 min for each participant.

3.1.4. Data analyses

Kinematic data were recorded during 2 s, from the go-signal until the end of each trial, with a sampling frequency of 100 Hz using an Optotrak 3020 (Northern Digital, Waterloo, Canada) 3D motion tracking system, which recorded the positions of three Infrared Emitting Diodes (IREDs) that were attached to the cylinder, which acted as a rigid body (see Bouwhuisen, Meulenbroek, & Thomassen, 2002). Data were filtered using a dual-pass, second-order, low-pass Butterworth filter with a cut-off frequency of 8 Hz. Missing data were interpolated. The beginning and end of the responses were defined as the first and last local minimum in the cylinder's tangential velocity pattern where the velocity reached a threshold value of 5% of the maximal velocity in that trial. Signed error served as the dependent variable and was calculated as the absolute difference between the requested rod orientation and the observed cylinder orientation when the movement was complete. The effects of frame- and rod-orientation on the signed errors were evaluated using a repeated-measures ANOVA with Angular difference as the independent variable.

3.2. Results

A one-way repeated measures ANOVA with Angular difference (5 levels; 0°, 5°, 10°, 15°, 20°) as a within-subjects variable and absolute signed error as the dependent variable yielded a significant main effect, $F(4,8) = 7.29$, $p < .01$. Pairwise comparisons showed that a 0° angular difference between rod and frame produced a significantly smaller absolute signed error than the other conditions (all p's $< .01$). The 20° angular difference resulted in a significantly larger absolute signed error than the other conditions (all p's $< .05$). The remaining pairwise comparisons did not show significant differences. Fig. 5 displays the participants' mean absolute signed errors as a function of angular difference.

3.3. Discussion

Experiment 2 examined how a rod and frame display would affect perceived misalignment of the rod when the degree of misalignment is expressed using a motoric response. If motor processing is not affected by the RFI, we should have found little or no influence of the RFI on perceived misalignment in this task. Wedid find such an influence. When the angular difference between the rod and frame was zero, participants made on average a 3.5° error, and this error increased significantly as the angular difference between the rod and frame also increased. It should be noted, however, that the main effect was based entirely on performance in the 0° and 20° conditions.

In sum, this second experiment shows that people are sensitive to the RFI when they express the misalignment that they are perceiving via a motoric response.

4. General discussion

In two experiments we showed that people are affected by an orientation illusion regardless of the type of response they have been asked to produce. More specifically, the tilted frame that we presented surrounding a rod induced a misperception of the rod's orientation. This demonstrates that participants based their responses on the orientation of the rod in relation to the frame. From the common representation model as proposed by Franz et al. (2001), we expected that the Rod-and-Frame Illusion (RFI) would show similar effects on different perceptuomotor tasks. Even though the required responses relied on both perceptual and motoric processes, the degree to which they were perceptual or motoric varied considerably. The two-alternative forced-choice task in Experiment 1 relied less on motoric processing than the parametric alignment task in Experiment 2. Both experiments yielded a significant increase in perceived misalignment as a function of angular difference, showing that the sensitivity to the RFI is indeed similar, regardless of the type of response.

Our results thus support the theory of a common representation as suggested by Franz et al. (2000, 2001), and

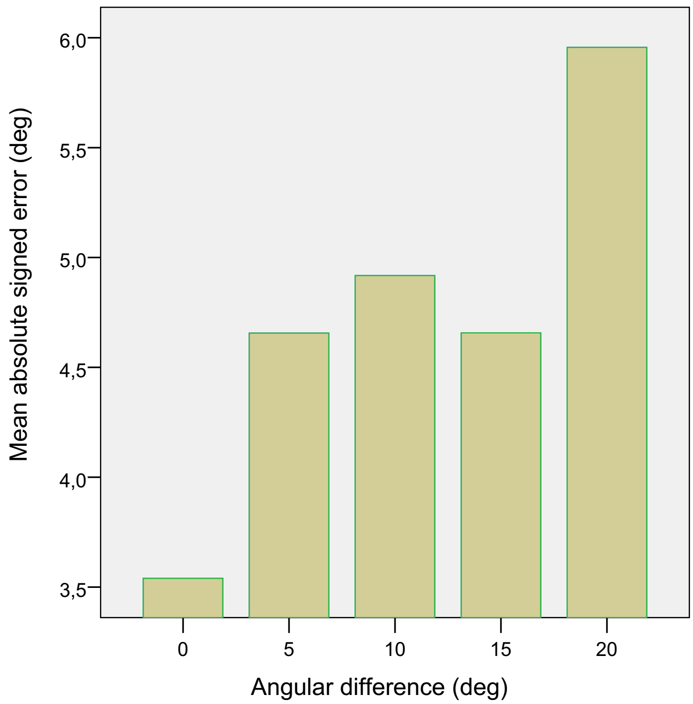

Fig. 5. Experiment 2, graph of mean (absolute) signed errors for all participants as a function of (absolute) angular difference between rod and frame.

Franz (2003). The common representation theory predicts similar effects of visual illusions on perceptual and motor tasks, provided that the different tasks are adequately matched. In addition, these results are in line with Bridgeman's work on frame displacements. Bridgeman (Bridgeman et al., 1981; Bridgeman, Peery, & Anand, 1997) found when a frame was laterally shifted, a misperception of the position of a target within that frame (known as the Roelofs effect) was induced in the opposite direction. More to the point, Bridgeman et al. also demonstrated that with a 2 s response delay, the Roelofs effect was present both when judgments relied more on motoric processing and when they were less reliant on it (Bridgeman, Gemmer, Forsman, & Huemer, 2000). Motor memory, which is thought to be represented in the dorsal visual stream, decays more rapidly in the absence of visual feedback than do the cognitive representations associated with the ventral stream (Bridgeman et al., 2000; Rossetti & Pisella, 2002). Because visual representations in the dorsal stream are short-lived, memory-based responses after a delay have to rely—at least partly—on the visual information being processed in the ventral stream (Rossetti & Pisella, 2002). Ventral stream processing is thought to use an allocentric frame of reference and to be more susceptible to contextual effects. In the present study, 1 s delayed responses show robust and constant RFI effects across perceptual and motor tasks.

To sum up, the present studies clearly demonstrate the Rod-and-Frame Illusion in two different tasks: there is context-sensitive misperception of rod orientation in more perceptual as well as in more motoric judgments. In both tasks, knowledge about the orientation of the rod was required to perform correctly. Furthermore, because the timing of the stimulus events was kept constant in both tasks, the same information about rod orientation was available for response processing. This information was clearly biased by the orientation of the surrounding frame. Our data suggest that the effects of visual illusions do not necessarily depend on the perceptual or motoric nature of the task, but rather on the information that is required to perform a specific task correctly, and on the information that is available to perform that task.

Knowing about systematic biases in human perception of tilted, framed objects is not just important for ergonomically framing speedometers (Camarillo, Krummel, & Salisbury, 2004; Simmonds, 1983) or for designing appropriate feedback displays to communicate the orientation of laparoscopic instruments during surgery (Berguer, 1998). It is also relevant for understanding and predicting joint action when handling objects of varying orientations. In particular, the end-state comfort effect, often assessed by means of bar-orientation tasks, is currently being investigated in the context of interpersonal coordination (Herbort, Koning, Uem, & Meulenbroek, 2012) and insights into perceptual biases of tilted objects are relevant for such behavioral studies. Tests of the impact of perceptuomotor rules such as end-state comfort in (i) individual tasks (Rosenbaum & Jorgensen, 1992), (ii) interlimb coordination tasks (Janssen, Beuting, Meulenbroek, & Steenbergen, 2006; Weigelt, Kunde, & Prinz, 2006), and (iii) tasks involving interpersonal coordination will demonstrate, at various time scales (see Fig. 1), the predictive power of orientation-dependent perceptuomotor rules. The present study of context effects on orientation perception should contribute to this ongoing program of research.

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