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ORIGINAL ARTICLE

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Abstract The present study examined if and how the direction of planned hand movements affects the perceived direction of visual stimuli. In three experiments participants prepared hand movements that deviated regarding direction ("Experiment 1" and "2") or distance relative to a visual target position ("Experiment 3"). Before actual execution of the movement, the direction of the visual stimulus had to be estimated by means of a method of adjustment. The perception of stimulus direction was biased away from planned movement direction, such that with leftward movements stimuli appeared somewhat more rightward than with rightward movements. Control conditions revealed that this effect was neither a mere response bias, nor a result of processing or memorizing movement cues. Also, shifting the focus of attention toward a cued location in space was not sufficient to induce the perceptual bias observed under conditions of movement preparation ("Experiment 4"). These results confirm that characteristics of planned actions bias visual perception, with the direction of bias (contrast or assimilation) possibly depending on the type of the representations (categorical or metric) involved.

Introduction

There is increasing evidence that monocular and binocular visual factors are not sufficient to explain the subjective awareness of visual space. For example, hills are judged steeper if people are encumbered by wearing a heavy backpack (Bhalla & Proffitt, 1999). Using a tool to extend one's reaching ability causes a compression of the subjective representation of a target distance, whereby a target appears closer to the actor (e.g., Berti & Frassinetti, 2000; Farnè & Làdavas, 2000; Longo & Lourenco, 2006; Witt, 2011; Witt & Proffit, 2008; Witt, Proffitt, and Epstein, 2005). In sport, motor performance correlates with the judgments of spatial attributes such as of goals or balls (Witt & Dorsch, 2009; Witt et al. 2008; Witt, Linkenauger, Bakdash, and Proffitt, 2005).

Findings like these are the cornerstones of action-oriented accounts of perception which suggest that the initial sensory information has to be "rescaled" or "enriched" by information related to intended actions to become meaningful to the perceiver (Witt, 2011; Witt & Proffitt, 2008; Witt, Proffitt, and Epstein, 2010; cf. also Scheerer, 1984 and Viviani, 2002 for historical reviews of related approaches). In spite of evidence supporting this basic idea (but see e.g., Durgin et al., 2009; Holmes, Calvert, and Spence, 2004; Shaffer & Flint, 2011; Woods, Philbeck, and Danoff, 2009 for criticism and alternative views), the assumed interaction between early sensory and motor variables is not well understood. Several motor variables, such as "effort" (cf. e.g., Witt et al., 2010), "reaching ability" (e.g., Witt, 2011), "action potential" (e.g., Witt et al., 2008), "joint size" (Linkenauger, Witt, and Proffitt, 2011) and "eye-height" (Twedt, Crawford, and Proffitt, 2012) are suggested to affect perception. Also, several sensory characteristics, such as distances (Proffitt, Stefanucci, Banton, and Epstein, 2003), object's size (Witt & Dorsch, 2009), object's height (Twedt et al., 2012), object's orientation (Gutteling, Kenemans, and Neggers, 2011) and slopes (Bhalla & Proffitt, 1999) were shown to be susceptible to motor influences. However, possible relations across all of these variables as well as possible

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relations of findings across distinct paradigms have been rarely investigated so far. This makes it difficult to predict a specific pattern of results in advance, if a new motor or sensory variable is considered.

We recently tried to define the mentioned assumption more precisely to derive and test explicit predictions (Kirsch & Kunde, 2012). We basically suggested that the impact of motor variables on sensory processing is mediated by the content of a current action plan. Adopting a strict motor view on perception one may agree that sensations are *always* scaled by certain motor variables. If so, then the question arises which motor variables are involved in a particular situation? According to the motor-planning hypothesis, these variables are an integral part of a motor plan used in this situation. This seemingly simple assumption allows testing interesting predictions. For instance, may such a variable like "effort" previously discussed in the context of extrapersonal space play a role in perception of near space? The motor-planning hypothesis suggests that this is the case as long as effort variables may be assumed to be specified during planning a motor act in this space. For simple reaching movement, this can be assumed to be valid (e.g., Flash & Hogan, 1985; Harris & Wolpert, 1998; Uno, Kawato, and Suzuki, 1989) and in two recent studies we in fact observed results which are compatible with this prediction (Kirsch, Herbort, Butz, and Kunde, 2012; Kirsch & Kunde, 2013). Participants prepared a hand movement, the costs of which were manipulated by a force device and/or by instructed movement amplitude. Before movement execution, they were asked to estimate a target distance. We observed that both the amplitude manipulation and the force manipulation affected distance judgments under certain conditions. Basically, larger costs of planned movements were associated with larger distance estimates.

While it is reasonable to conceive that both movement amplitude and force are linked to movement "costs", this creates ambiguity as well. Can characteristics of planned movements affect visual space perception in itself, despite constant metabolic costs that come with these movements? Answering this question requires a manipulation of movement characteristics while leaving movement costs essentially unaltered. This is what we aimed at in the present study. We manipulated movement direction, which is a feature that can be planned independent of movement extent (e.g., Gordon, Ghilardi, and Ghez, 1994). Specifically, we studied if planning movements of different directions affect the visual perception of directions in a similar manner as planning movement of different extents has been shown to affect the visual perception of distances. This question implicitly presupposes that a sufficient degree of similarity or overlap (e.g., Kornblum, Hasbroucq, and Osman, 1990) between motor characteristics and visual characteristics is necessary for such interactions to show up. In other words, while planned and perceived directions as well as planned and perceived distances may affect each other, it is less likely that planned distances and perceived direction affect each other (an assumption we test in "Experiment 3" below).

Although the impact of planned movement direction on the perception of visual directions has not been examined so far to our knowledge, there is some indirect evidence indicating that movement direction may induce changes in the perception of a target location. For instance, Wohlschläger (2000) demonstrated that the perceived direction of ambiguous apparent motion can be affected by the direction of simultaneously planned hand movement. Moreover, Zwickel, Grosjean, and Prinz (2010a) reported evidence for a reciprocal relationship between the perceived directions of a visual stimulus and of a concurrently executed hand movement (cf. also Grosjean, Zwickel, and Prinz, 2009). In the following, we present four experiments which extend these results indicating plasticity of perception of a visual location depending on planned movement direction.

Experiment 1

Participants received a cue that informed them about the direction of a movement to be carried out after a subsequent perceptual judgment. Movements were planned 15 or 45 degrees clockwise or counterclockwise to the direction of a visual stimulus. The perceptual judgment required participants to align a short line to the direction of that visual stimulus. We tested whether the planned movement direction would modulate perceived stimulus direction.

Assuming that the impact of planned direction on perceived direction is equivalent to the impact of planned distance on perceived distance, one can predict an assimilation bias (Kirsch et al., 2012; Kirsch & Kunde, 2012). That is, if a movement to the right is required, participants should judge the stimulus position as being more right as compared to movements aiming at the left side of the stimulus. This would be in line with the results of Wohlschläger (2000) who showed that the perceived direction of apparent motion (e.g., clockwise) was biased by simultaneously performed movements in the direction of movement (e.g., clockwise; cf. "Experiment 1"). Lindemann and Bekkering (2009) also reported an assimilation bias: planning to grasp and rotate an object facilitated the detection of congruent visual apparent motion.

However, we should be equally prepared to encounter a contrast bias, such that planned movements to the right bias perceived stimulus directions to the left compared to movement planned to the left. Müsseler and Hommel

(1997), e.g., demonstrated that the discrimination of masked arrow direction (e.g., right) is reduced during planning of a compatible (i.e., of a right) button press. In a similar vein, Zwickel et al. (2010a) reported contrast effects in a task that required encoding of stimulus motion direction while performing hand movements in an instructed movement direction.

Both, assimilation and contrast phenomena were observed in designs, in which either the impact of perception on action or of action on perception was investigated (see e.g., Shin, Proctor, and Capaldi, 2010, and Zwickel & Prinz, 2012, for reviews). In a recent attempt to resolve some discrepancies, Zwickel and Prinz (2012) suggested that contrast effects "occur only when two functionally unrelated tasks are performed at the same time, no perceptual ambiguity or rhythm is involved, and the tasks share common features". In terms of the authors the present perception and action tasks are rather functionally unrelated since planning a movement was not directly related to the judged target position. Also, both tasks are rather concurrent, i.e., simultaneously executed. Accordingly, based on this approach, a contrast bias can be expected. Also, Thomaschke and colleagues (Thomaschke, 2012; Thomaschke, Hopkins, and Miall, 2012) argued that the impact of motor planning on perception is primarily mediated by categorical action features and is associated with contrast effects. Motor control processes including metric representations, on the other hand, produce assimilation biases. Following this account, also a contrast effect can be predicted because in the present design motor planning, but not motor control processes could affect perceptual judgments.

Methods

Participants

Twenty participants were recruited. They gave their written informed consent for the procedures. The sample included 17 females and 3 males, all of them reported to be right handers. The mean age was 25 years ranging from 18 to 31 years.

Apparatus

The apparatus consisted of a digitizing tablet (Wacom Intuos 2 A4), a digitizing stylus, a monitor and a semi-silvered mirror (see Fig. 1 in Kirsch et al., 2012). The tablet was placed on a table. The monitor was positioned approximately about 48 cm above the tablet. The mirror was in between the tablet and the monitor, so that it was approximately equidistant with respect to the tablet and the monitor. In the laboratory the light was dimmed during the experiment. Under these lighting conditions, the mirror prevented the vision of the arm and allowed projections of virtual images in the plane of the tablet. We did not manipulate visual feedback during movement execution. That is, the stimulus position indicating the position of the stylus approximately corresponded to the real stylus position. The size of one picture element (PEL) on the screen was about 0.38 mm.

Procedure and design

Participants' position of the body midline corresponded with the middle of the monitor and of the tablet. We also asked the participants to lean their forehead on an upper part of the main apparatus to keep the position of the head constant.

The main trial events are schematically illustrated in Fig. 1. Each trial started with a movement of the stylus to the start position (red point of 1.5 mm in size). The start position was in the middle lower part of the tablet. After the start position was reached, the participant had to press a stylus button. Following this button press, a symbolic cue appeared (see Fig. 1, left). This cue included an alphabetic character ("L" or "R") and a digit ("15" or "45") and informed the participant about the movement that had to be executed after the following judgment of stimulus position. The characters and the digits were ~ 1 cm in size and white in color. They were framed by a black rectangle of size 9.5×7 cm. The residual display was gray. The characters indicated the direction of the movement relative to the current target position (L = left, R = right), whereas the digits reflected the angular deviation of the movement end point from the target (15° and 45°).

After the participant pressed the space bar, the cue disappeared and a target stimulus appeared together with a line initially oriented in depth (see Fig. 1, middle part). The line was gray and had a length of ~ 5.7 mm and a thickness of ~ 0.4 mm. By pressing a right and a left arrow key participants had to change the orientation of the line so that it was exactly directed toward the current target stimulus. The left arrow key was used to deflect the line to the left, whereas the right arrow key was used to rotate the line to the right (the point of rotation was the lower end of the line that corresponded with the start position)[1].

The target was a gray point (~ 1.5 mm) that could appear at four positions henceforth labeled as A, B, C and D from left to right. The distance between each target and the lower end of the line was always about 13 cm (350

[1] The used sensitivity of the button presses to visible changes of line orientation included the possibility that a possible bias in estimates may not be accompanied by visible changes in line orientation. We, however, did not find any indices in the data that could confirm this assumption.

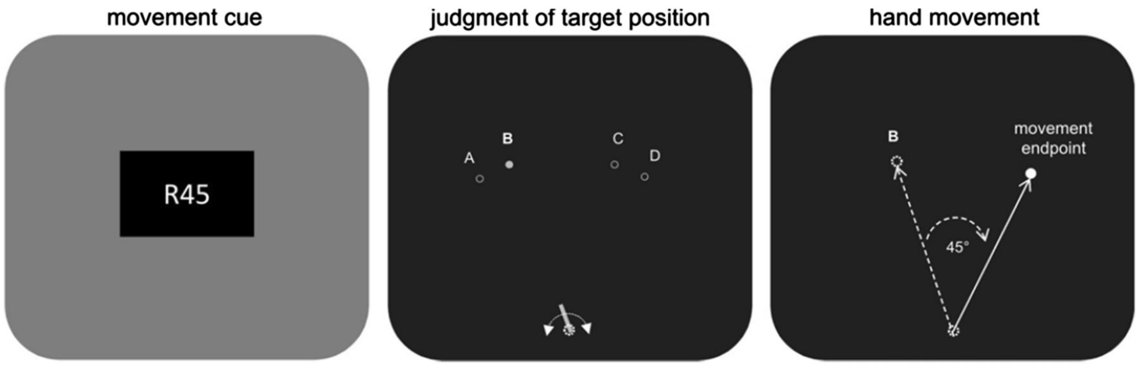

Fig. 1 Schematic illustration of the trial procedure. Note, *unfilled circles* shown in the *middle* are potential target positions, which were not visible in this example. During the hand movement only the virtual position of the stylus was presented in the form of a green point. The movement cue requires participants to prepare a movement that should deviate from a given target (*B*) to the right by 45°

PEL). That is, the targets were positioned on an imaginary semi-circle with a center at the start position. With respect to the start position, two targets were on the left side of the display and two other targets on the right side. The angular deviations from the initial line orientation were −27°, −18°, +18° and +27° for the targets A, B, C and D, respectively (cf. Fig. 1, middle part).

The adjustment procedure was completed by pressing the enter key of the keyboard. In response to this key press, the line and the target disappeared and the current stylus position was displayed (green point of ~1.5 mm in size). This change of the display was a signal to initiate a stylus movement according to the movement cue presented before the judgment of target position. After the movement was finished a stylus button had to be pressed. Following this button press a red circle was presented at the starting position (see below), additionally to a short text that asked the participant to move the stylus back to the start position.

Participants were asked to perform stylus movements with their dominant hand, whereas position judgments had to be performed with the non-dominant hand.

The experiment included three independent variables: target position (4 levels—A, B, C, D), instructed movement direction (2 levels—left, right) and the instructed magnitude of deviation (2 levels—15°, 45°). There were four blocks of trials with 16 trials each. In each block, each combination of target and movement instruction conditions was presented once in a randomized order. At the beginning of the experiment participants performed four practice trials, which were not included in the analyses.

Data analysis

To measure the accuracy of perceptual judgments, the angular difference between the adjusted orientation of the line and real angular position of the target was computed (constant perceptual error). By definition, positive perceptual error reflects the tendency to direct the line to the right of the target, whereas negative perceptual error indicates the tendency to direct the line to the left of the target. The coordinates of movement end points were used to compute movement extent (movement amplitude) and the angular deviation from the given target (end point deviation). Movement amplitude was defined as a linear distance between the stylus position after reaching the starting position and the stylus position after reaching the movement end point. End point deviation was the angle between two imaginary lines. One of them linearly connected the starting position with the movement end point. The other line was the linear distance between the starting position and the given target. Positive angles reflect rightward deviations of movement end points from the targets, while negative angles reflect leftward deviations.

Trials, in which position judgments deviated by more than 10° from the target position were considered as outliers and excluded from analyses. Also, trials in which movement amplitude was less than 200 PEL were discarded. Moreover, trials, in which participants performed movements in the opposite direction (i.e., if movements to the left of the target were required, but movements to the right were performed and vice versa) did not enter the analyses. For the remaining trials (95.2 %) the mean perceptual error, mean movement amplitude and the mean end point deviation were computed for each participant and each experimental condition.

Results

Motor performance

Table 1 shows the mean movement characteristics. To ensure that participants followed the movement instructions, two analyses of variance (ANOVAs) were performed

Table 1 Mean angular deviation of movement end point from the target position and mean movement amplitude in each experimental condition of Experiment 1

Target	Angular deviation(°)				Movement amplitude (PEL)			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Movement instruction								
L15	−13.51 (4.20)	−14.10 (4.13)	−12.90 (4.13)	−12.80 (4.33)	358 (17)	360 (18)	365 (16)	363 (19)
L45	−32.88 (8.30)	−33.15 (7.26)	−31.87 (9.37)	−32.71 (8.17)	352 (30)	359 (31)	367 (21)	364 (26)
R15	13.43 (4.59)	13.20 (4.03)	14.18 (5.19)	13.77 (3.63)	357 (20)	358 (18)	355 (14)	354 (19)
R45	34.62 (5.87)	33.93 (7.36)	32.40 (8.75)	32.19 (9.30)	358 (24)	362 (25)	351 (23)	349 (28)

Standard deviations are shown in parentheses

with target position, instructed movement direction and instructed magnitude of deviation as factors and end point deviation and movement amplitude as dependent measures. For angular deviation, these analyses revealed a significant main effect for instructed movement direction, $F(1, 19) = 463.5$, $p < .001$, $\eta_p^2 = .961$, and a significant interaction between instructed movement direction and the instructed magnitude of deviation, $F(1, 19) = 212.8$, $p < .001$, $\eta_p^2 = .918$. Participants performed movements as required by the instruction underestimating, however, the required deviation magnitudes of 45 and 15° (cf. Table 1). In the analysis of movement amplitude, a main effect of instructed movement direction was significant with $F(1, 19) = 7.1$, $p = .016$, $\eta_p^2 = .271$. This result indicated a slight tendency (6 PEL) toward a decrease of movement amplitude for the rightward movements as compared to the leftward movements (cf. Table 1). On average, movement amplitude (358 PEL) corresponded quite exactly with target distance (350 PEL). Thus, by and large, the implemented manipulation of motor parameters was successful.

Constant perceptual error

An ANOVA computed with the constant perceptual errors as dependent variable and with target position, instructed movement direction and instructed magnitude of deviation as factors revealed significant main effects of target position, $F(3, 57) = 16.6$, $p < .001$, $\eta_p^2 = .466$, and instructed movement direction, $F(1, 19) = 6.3$, $p = .021$, $\eta_p^2 = .249$ (all other $p \geq .167$). Figure 2 illustrates the mean perceptual errors for each target and for both movement direction conditions.

Targets shown on the left side of the display (A and B) were judged to be on the right of their real position, whereas targets on the right side of the display (C and D) were judged to be on the left of their real position. These biases were more pronounced for the outer targets. More importantly, participants judged the direction of the target to be more right when they planned a movement directed to

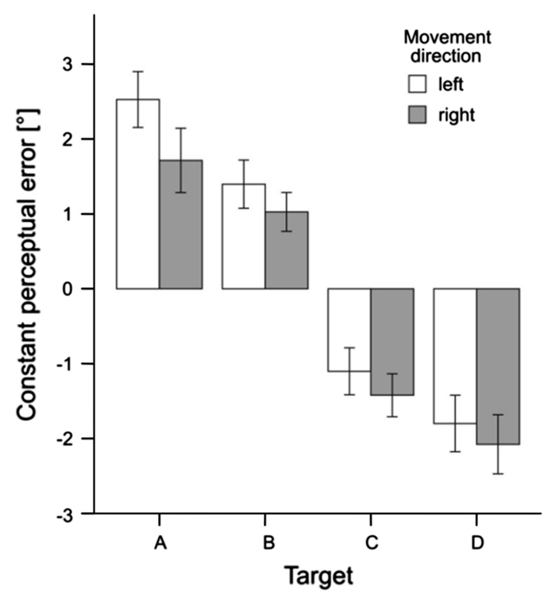

Fig. 2 Main results of Experiment 1. Mean constant error as a function of movement direction for each target position. *Error bars* are standard errors

the left side of the target than when they planned a movement directed to the right side of the target.

Discussion

The manipulation of planned movement direction affected judgments of stimulus directions. However, unlike influences of movement distances on perceived stimulus distances, we found a contrast effect rather than an assimilation effect: planning a movement to the right biased the perception to the left. This result confirms the hypothesis that contrast effects should emerge when concurrent but otherwise unrelated perceptual and motor tasks share similar features (Zwickel & Prinz, 2012). Also, the present result is in line with the model of Thomaschke and colleagues (Thomaschke, 2012; Thomaschke et al., 2012), suggesting that action planning generally exerts an inhibitory influence on perceptual processing, whereas the effect of action control processes on perception is rather facilitative. However, the results of our previous studies which were conceptually similar, but which revealed assimilation biases, do not seem to support these conclusions. We return to this issue in "General discussion".

Another observation of Experiment 1 was the tendency toward the center of the screen during the judgments of target position. This result probably reflects an inertia bias toward the initial orientation of the line used for position estimates, because participants finished the adjustment procedure as soon as the line was directed approximately close to the real target position. Also, due to a small convexity of the monitor some optical distortions cannot completely be ruled out, which can possibly explain this bias. However, since the visual context was identical for all movement conditions, this result does not seem to limit possible conclusions about movement planning.

Altogether, despite the direction of the observed effect the results can be considered as another hint for the motor-planning hypothesis mentioned in the introduction. There are, however, some caveats, which may complicate possible conclusions.

First of all, the results may reflect the impact of planned movement direction on the act of judgment rather than on perception of target. For instance, planning a movement to the right of the target may suppress a right button response to some extent that in turn may lead to a leftward bias of judgment. To test this possibility we performed Experiment 2.

Experiment 2

Experiment 2 was identical to Experiment 1 except for the assignment of buttons to the direction of line rotation during judgments. Pressing a left button caused a rotation of the line to the right now, and conversely a right button was used to rotate the line to the left.

We aimed to decide between two hypotheses. The direction of the effect of movement direction on judgments observed in Experiment 1 will be reversed if the effect would be related to an interaction between planning a hand movement and pressing a button during judgments (i.e., to a response–response interaction). In contrast, if a pattern of results can be observed that is similar to that of Experiment 1, then the results will indicate action-dependent changes in perception rather than in judgments.

Methods

Participants

Twenty-two participants were recruited. They gave their written informed consent for the procedures and received an honorarium or course credit for their participation. One participant had a visual impairment, while another participant seemed to misunderstand the task instruction[2]. Their data were excluded from analyses. The final sample included 14 females and 6 males. The mean age was 27 years, ranging from 20 to 52 years (SD = 7). All participants apart from one reported to be right handed.

Procedure

The procedure of Experiment 2 was identical to the procedure of Experiment 1 with one exception. During the adjustment procedure, the left arrow key was now used to move the line to the right, whereas the right arrow key was used to deflect the line to the left.

The apparatus as well as the experimental design was the same as in Experiment 1. Also, the data analyses were performed in the same way as in Experiment 1. After the initial preprocessing stage, 93.8 % of trials entered the analyses.

Results

Motor performance

An analysis of produced end point deviations revealed a significant main effect of instructed movement direction, $F(1,19) = 343.1$, $p < .001$, $\eta_p^2 = .948$, and a significant interaction between instructed movement direction and the instructed magnitude of deviation, $F(1, 19) = 149.9$, $p < .001$, $\eta_p^2 = .887$, indicating an adherence to the movement instruction. Additionally, however, participants tended to decrease the magnitude of produced deviation for targets which were on the right side of the display when movements to the right were required. For movements to the left side of the target, such a trend was not observed (here, a rather opposite trend was evident). This was expressed in a significant target position × instructed movement direction interaction, $F(3, 57) = 4.7$, $p = .006$, $\eta_p^2 = .197$ (see Table 2 for means).

Movement amplitude systematically varied to some extent depending on the target position, instructed movement direction and instructed magnitude of deviation as indicated by a significant interaction between these factors, $F(3, 57) = 16.9$, $p < .001$, $\eta_p^2 = .470$. Participants generally tended to decrease the amplitude of movements for left targets when they performed movements to the left of the targets as compared to movements to the right. For the target positions on the right side of the display, in contrast,

[2] Mean movement amplitude was more than 2 SD above the mean of the sample.

Table 2 Mean angular deviation of movement end point from the target position and mean movement amplitude in each experimental condition of Experiment 2

Target	Angular deviation(°)				Movement amplitude (PEL)			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Movement instruction								
L15	−16.42 (5.32)	−16.10 (5.13)	−15.76 (5.54)	−17.27 (5.84)	357 (26)	357 (27)	360 (19)	361 (20)
L45	−35.58 (10.81)	−35.44 (10.11)	−35.75 (8.97)	−37.87 (9.96)	338 (45)	343 (54)	369 (23)	361 (27)
R15	16.72 (7.81)	14.60 (6.38)	14.49 (5.25)	13.51 (4.97)	363 (21)	363 (22)	356 (28)	358 (27)
R45	37.08 (10.13)	36.45 (9.60)	33.59 (9.27)	33.87 (9.94)	363 (33)	364 (27)	344 (42)	337 (42)

Standard deviations are shown in parentheses

they decreased the amplitude when they performed movements to the right side of the targets. This effect was reduced for the small magnitude (15°) as compared to the large magnitude (45°) conditions.

Constant perceptual error

As in Experiment 1, an ANOVA performed on the constant perceptual errors including target position, instructed movement direction and instructed magnitude of deviation as factors yielded significant main effects of target position, $F(3, 57) = 41.0$, $p < .001$, $\eta^2_p = .683$, and instructed movement direction, $F(1, 19) = 5.3$, $p = .033$, $\eta^2_p = .217$. Additionally, however, a target position × instructed movement direction interaction was also significant with $F(3, 57) = 3.8$, $p = .014$, $\eta^2_p = .168$ (all other $p \geq .477$). Figure 3 shows mean perceptual errors according to the four target and both movement direction conditions.

Analogously to the results of Experiment 1, there was a tendency to judge target positions to be on the right side of their real positions, when targets were on the left side of the display, and conversely to be on the left side of the real positions, when targets were on the right side of the display. Also, these biases tended to be more strongly pronounced for outer targets. Significant differences were observed between A and C, A and D, B and C, and B and D as indicated by pairwise comparisons (all $p < .001$).

More importantly, participants judged the position of the target to be more right when they planned a movement directed to the left side of the target compared to planning a movement to the right side of the target. This, however, was significant only for targets which were on the left side of the display. Post hoc analyses (ANOVAs with instructed movement direction and instructed magnitude of deviation as factors) indicated significant movement direction effects for the target A ($p = .013$) and B ($p = .007$), but no effects for the targets C ($p = .249$) and D ($p = .991$).

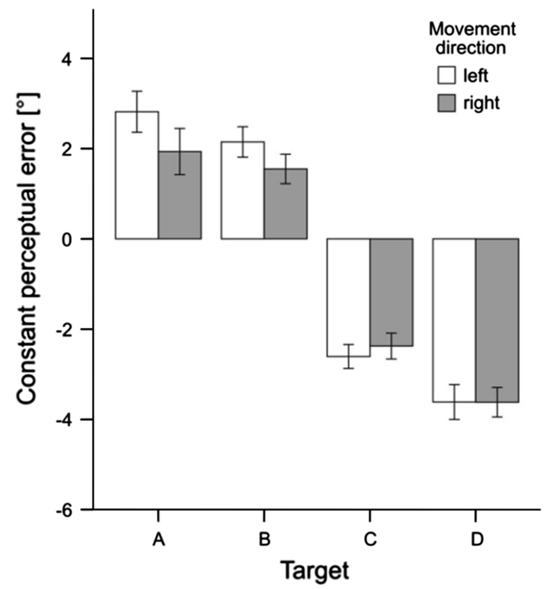

Fig. 3 Main results of Experiment 2. Mean constant error as a function of movement direction for each target position. *Error bars* are standard errors

Discussion

The main result of Experiment 2 was that an incompatible assignment of buttons to the direction of line rotation during perceptual estimates did not essentially change the pattern of results observed in Experiment 1. We observed that when the targets appeared on the left side of the display, planning a hand movement directed to the right of the target biased the judgment to the left as compared to planning a movement to the left of the current target position. When the targets were on the right side of the display, we did not find any differences across the movement instruction conditions. A decrease in the observed effect from the left to the right target position was also evident in Experiment 1; however it was not expressed in a significant interaction between target position and instructed movement direction. Since there were some minor differences in motor behavior between the two experiments, we suppose that differences in planning strategies may account for the slightly different outcomes in judgments. Also, we can only speculate why the predicted effect predominantly occurred on the left side of the display. Some changes in movement planning associated with biomechanical factors may have possibly contributed to this result. Since the movement was performed with the right hand, the movements to the left and to the right side were associated with quite distinct patterns of joint motions and muscles activations. Thus, planning strategies applied for each side of the display may have been more or less consistent within and across participants and this may have led to a reduced impact on perception of target position on the right side of the display.

In any case, because a possible reversal of the direction of the effect found in Experiment 1 was not observed, the data suggest that the perceived orientation of the target was affected by the manipulation of planned movement parameters in both experiments rather than the judgment per se.

There may be, however, other caveats that may limit possible conclusions, for example, the cue used in Experiment 1 and Experiment 2 as movement instruction may have affected target judgments rather than the assumed motor-planning processes.

Experiment 3

Considering the current experimental setup one may argue that the mere appearance of an alphabetic character and/or a digit before a perceptual judgment biases this judgment in a certain direction (cf. Kirsch et al., 2012). For instance, the character "R" may activate an association with the spatial dimension "right", whereas the character "L" may activate an association with the dimension "left". Analogously, a small number may be more strongly associated with the spatial dimension left than a large number (cf. e.g., Dehaene, Bossini, and, Giraux, 1993). Accordingly, the results of Experiments 1 and 2 may merely reflect the impact of such associations on perceptual judgments. For instance, the observed effect of movement direction on perceived target position might be due to automatic activation of spatial dimensions "left" and "right" through the processing of the cue rather than due to certain planning processes of movement. Moreover, a possible interaction between the spatial associations related to the characters and letters may explain why magnitude of deviation had no influence in the previous experiments. That is, the apparent effect of movement direction might have emerged because in "spatially incompatible" cue conditions (i.e., when the cue was "R15" or "L45") the impact of the cue was reduced as compared to "spatially compatible" conditions (i.e., when the cue was "R45" and "L15"). To explore these possibilities was one goal of Experiment 3.

Additionally, we aimed to test if other movement parameters than movement direction affect direction estimates in the current setup. This question refers to the issue of the relation across sensory attributes and motor variables raised in "Introduction" (i.e., to the question which sensory characteristics are affected by which motor characteristics). Conceivably, we assumed that a sufficient degree of commensurability or overlap (e.g., Kornblum et al., 1990) is necessary. That is, those sensory aspects of a stimulus are biased or enriched by features of motor actions, which are conceptually related to these features. For instance, planning an effortful movement (compared with planning a less effortful movement) toward a target should bias the perceived target location along the planned movement path (e.g., along the depth dimension), but not along another stimulus dimension (e.g., along the horizontal dimension)[3]. In contrast, a variation in planned movement direction should bias the perception of stimulus across the planned directions (e.g., along the horizontal dimension), but not along the other dimensions (e.g., along the depth dimension). Some support for this assumption comes from the study of Zwickel, Grosjean and Prinz (2010b, "Experiment 2"), who tested the influences of movement effort on direction judgments of concurrently presented visual motion. In contrast to our study (Kirsch & Kunde, 2012) indicating systematic effort-related modulations of distance judgments, no significant impact of force variation on perceived direction of visual motion was found.

To examine this issue, we assigned a different movement instruction to the cues. Participants were now asked to perform movements aiming at over- and undershooting of the target by a varying degree, whereas the general experimental procedure remained the same as in both the previous experiments. We expected to find no significant variation in perceptual judgments depending on movement instruction.

Methods

Participants

Twenty right handed subjects participated. They gave their written informed consent for the procedures and received

[3] Please note that we treat possible perception–action interactions in the tradition of action-related approaches of perception suggesting that motor processes constitute a kind of reference according to which sensory signals are scaled to form subjective perception (cf. Introduction). Within this tradition several "motor" variables may act as a "ruler" enriching perceptual experience (cf. e.g., Proffitt & Linkenauger, 2013) and, thus, in theory, all of them may have a sensory mapping in perception. Because effort is closely related to forces driving the joint along a given movement direction, its impact on sensory processing may be assumed to spread out along this trajectory.

an honorarium or course credit for their participation. The mean age was 25 and ranged from 19 to 37 years. This sample included 16 females and 4 males.

Apparatus

The same apparatus was used as in Experiment 1 and Experiment 2.

Procedure and design

Participants saw the same movement cues as in Experiment 1 and Experiment 2 (i.e., L15, L45, R15 and R45). The characters and digits, however, were provided with different movement characteristics as compared to the previous experiments. The characters ("L" and "R") now indicated a movement, the amplitude of which should be smaller or larger than the distance between the start position and the target. The assignment of characters to these movement tendencies was counterbalanced across the participants. The digits ("15" and "45") stood for the magnitude in mm by which a target position should be over- or undershot by a movement. Each movement had to be performed in the direction of the target. The adjustment procedures as well as other details of the trial procedure were identical to those of Experiment 1.

Data analysis

The preprocessing of perceptual and motor responses was performed in a similar way as in Experiment 1 and Experiment 2. Trials in which movement amplitude was less than 50 PEL, participants showed an overshooting of the target instead of its undershooting and, vice versa, judgment position errors of more than 10° were removed from the analyses (5 % of trials).

In a first analysis, we examined the impact of movement cue on position judgments. For this purpose, we analyzed the data analogously to the previous experiments including character direction (R, L), digit magnitude (15, 45) and target position as factors. In a second analysis, we aimed to test the impact of movement instruction. Accordingly, the data were analyzed including instructed movement deviation (under-, overestimation), the instructed magnitude of deviation (15 mm, 45 mm) and target position as factors.

Results

Movement cue

Movement cue affected neither motor responses nor perceptual judgments as indicated by nonsignificant effects for the factors character direction and digit magnitude in the corresponding ANOVAs.

Movement instruction

Motor performance Movement amplitude varied in accordance with the movement instruction as indicated by a significant main effect of instructed movement deviation (above vs. below), $F(1, 19) = 565.2$, $p < .001$, $\eta_p^2 = .967$, and a significant interaction between instructed movement deviation and the instructed magnitude of deviation (15 vs. 45 mm), $F(1, 19) = 187.8$, $p < .001$, $\eta_p^2 = .908$ (see Table 3 for means).

Constant perceptual error An ANOVA performed with the constant perceptual errors as dependent variable and with target position, instructed movement deviation and instructed magnitude of deviation as independent variables revealed a significant main effect of target position, $F(3, 57) = 35.6$, $p < .001$, $\eta_p^2 = .652$. Moreover, a marginally significant interaction between all of the factors was observed, $F(3, 57) = 2.5$, $p = .066$, $\eta_p^2 = .118$ (all other $p \geq .354$). Mean perceptual errors of all experimental conditions are shown in Fig. 4.

Similarly to the results of the previous experiments, a rightward bias was observed for the targets presented on the left side of the display. For the targets that appeared on the right side a leftward bias was evident. These biases tended to be reduced when movements were planned aiming at overshooting a target by 15 mm as compared to movements aiming at undershooting a target by 15 mm. For the 45 mm conditions, an opposite trend was observed.

Discussion

The data analyses of Experiment 3 revealed two main findings. First, the content of the cue did not affect perceptual judgments. This renders it unlikely that the results of Experiment 1 and Experiment 2 reflect an impact of cues

Table 3 Mean movement amplitude in each experimental condition of Experiment 3

Target	Movement amplitude (PEL)			
	A	*B*	*C*	*D*
Movement instruction				
a15	433 (31)	430 (31)	430 (22)	434 (20)
a45	499 (46)	500 (42)	496 (37)	506 (37)
b15	299 (17)	293 (16)	292 (18)	294 (17)
b45	229 (25)	224 (18)	222 (24)	227 (23)

Standard deviations are shown in parentheses

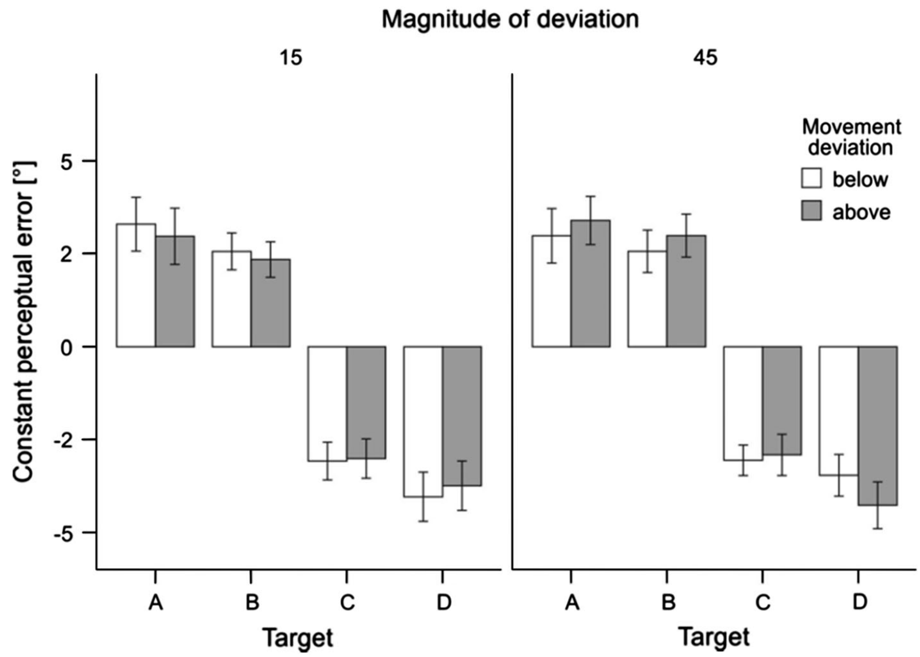

Fig. 4 Results of Experiment 3. Mean constant error for each experimental condition. *Error bars* are standard errors

(without corresponding motor planning) on direction estimates.

Second, a marginally significant interaction suggested that the planned over- and undershooting of the target affected the perceptual judgments rather systematically. For the relatively small magnitude of instructed movement deviation, participants judged the laterally located targets to be more central when they planned to overshoot the target as compared to planning to undershoot the target. For the relatively large movement deviation, there was an opposite trend. This result does not seem to fit the assumed principle of physical relevance between sensory and motor characteristics, because there was no obvious overlap between sensory (left–right) and motor (close–far) dimensions in the present experiment. It rather appears to support the notion recently stressed by Wykowska, Hommel and Schubö (2011) that action–perception interactions do not arise at (or at least are not restricted to) the low level of sensory and motor features, but may involve higher level representations related to action goals. The authors demonstrated an impact of action planning on perception in the absence of feature similarity between stimulus and response sets.

Experiment 4

The results of Experiment 3 indicate that the physical characteristics of the alphanumerical cues and their possible relations to spatial dimensions do not affect perceptual judgments of position in the present setup. However, it remains possible that the impact of instructed movement direction on position judgments observed in Experiment 1 and Experiment 2 is due to activation of explicit semantic codes (i.e., “left” and “right”) by the cue rather than directly related to movement planning. Moreover, it is well conceivable that shifting attention toward a space location alone may bias perception of a given object independently of movement planning (cf. e.g., Anton-Erxleben & Carrasco, 2013).

To examine this issue we replaced the movement phase of the previous experiments by a perceptual discrimination task. After each position judgment, participants had to make a decision about the identity of a letter (“L” or “T”) shortly presented at a certain location (i.e., 15° or 45° to the left or to the right of the current target position). Importantly, the same instructional cues as in the previous experiments were presented before each position judgment. These cues now indicated the probable location at which a letter will occur. Thus, an explicit coding of the cues in terms of semantics and a shift of attention in space can be assumed to take place here (as well as in Experiment 1 and Experiment 2). Accordingly, a similar pattern of results as in the first two experiments would suggest that the judgment bias of Experiment 1 was caused by semantic coding of cues and/or by spatial shifts of attention instead of movement planning.

Methods

Participants

Twenty participants participated. All of them were female. They gave their written informed consent for the procedures and received an honorarium or course credit for their participation. One participant seemed to misunderstand the instruction or to have a visual impairment that was not reported because her estimates consistently deviated from a target by about 10° on average. Her data were not included in the analyses. The mean age of the remaining participants was 23 and ranged from 19 to 39 years of age. All participants apart from one reported to be right handed.

Apparatus

The same apparatus was used as in the previous experiments. The stylus as well as the graphics tablet, however, was not actively used in this experiment.

Procedure and design

Before each position judgment, participants saw the same instructional cues as in the previous experiments (i.e., L45, L15, R15 and R45). These cues, however, now informed about a probable location at which a letter ("L" or "T", 3 mm in size and gray in color) will shortly appear following position judgment. The letter was presented for 100 ms, 500 ms after the confirmation of the position judgment (i.e., after the respective key press). The task was to indicate whether an "L" or a "T" was presented by pressing a left or a right key on a computer mouse. The mouse was placed to the right of the tablet. The assignment of the keys to the letters was counterbalanced across the participants.

The letters appeared 15° or 45° to the left or right of a judged target position. In ~73 % of trials, the instructional cue validly indicated the position at which the letter occurred. In the remaining trials, the letter was presented at one of the three other positions with equal probability (~9 %). There were 176 experimental trials. 128 of them contained valid cues [4 (target positions) × 4 (cued letter location) × 8 (repetition factor)]. The remaining 48 trials contained invalid cues [4 (target positions) × 4 (cued letter location) × 3 (real letter location) × 1 (repetition factor)]. The experiment was divided into four blocks with 44 trials each. At the beginning of the experiment, participants performed eight practice trials with valid cues which were not included in the analyses.

The adjustment procedures as well as other details of the trial procedure were identical to those of Experiment 1 except for a marginal change: during the adjustment procedure, the line was made slightly more sensitive to button presses (cf. Footnote 1).

Data analysis

Initially, trials in which judgment positions errors were more than 10° and in which response latencies in the discrimination task extended by 4 s were removed from the analyses (4 % of trials).

In a first analysis we tested whether participants followed the instruction and shifted their attention as required by the instructional cue of the discrimination task. For this purpose, we analyzed the response times in correct trials and error rates of this task using an ANOVA with the factors cued letter location (L45, L15, R15, R45) and real letter location (L45, L15, R15, R45).

In a second analysis, we then examined whether perceptual estimates of a given target position vary as a function of attentional instruction. Position judgment data were analyzed including instructed direction of attention (left, right), instructed deviation of attention (15°, 45°) and target position as factors.

Results

Discrimination task

Figure 5 illustrates mean response latencies and mean hit rates for the discrimination task. As predicted, when the instructional cue was valid (i.e., when it correctly indicated the real letter position) the discrimination performance was better compared to invalid conditions. An increase in spatial distance between the cued and the real location was associated with a decrease in performance. These observations are substantiated by two ANOVAs which revealed a significant interaction between the factors cued letter location and real letter location for the response times data, $F(9, 162) = 4.0, p < .001, \eta_p^2 = .180$, and for the accuracy data, $F(9, 162) = 7.3, p < .001, \eta_p^2 = .288$[4].

Position judgments

An analysis of position estimations (ANOVA) including instructed direction of attention (left, right), instructed deviation of attention (15°, 45°) and target position as factors only revealed a significant main effect for target position, $F(3, 54) = 21.1, p < .001, \eta_p^2 = .540$ (all other $p \geq .129$)[5]. Thus, attentional instruction did not significantly affect position judgments. Figure 6 shows mean values of this

[4] Two subjects failed to respond correctly in one of the invalid conditions. These missing response time values were replaced by the mean of the remaining participants in those conditions. Excluding these subjects from the analyses did not change the results (the critical interaction was still significant with $p = .002$).

[5] To evaluate to what extent this outcome might be due to trials in which attention was not shifted as required by the cue, we confined the same analysis to a subsample of all trials. In particular, trials with correct responses of the discrimination task in which the attentional cue was valid and error trials in which the cue was invalid were included (70 % of trials). This more conservative procedure which resembles the outlier rejection of the previous experiments did not substantially change the pattern of results.

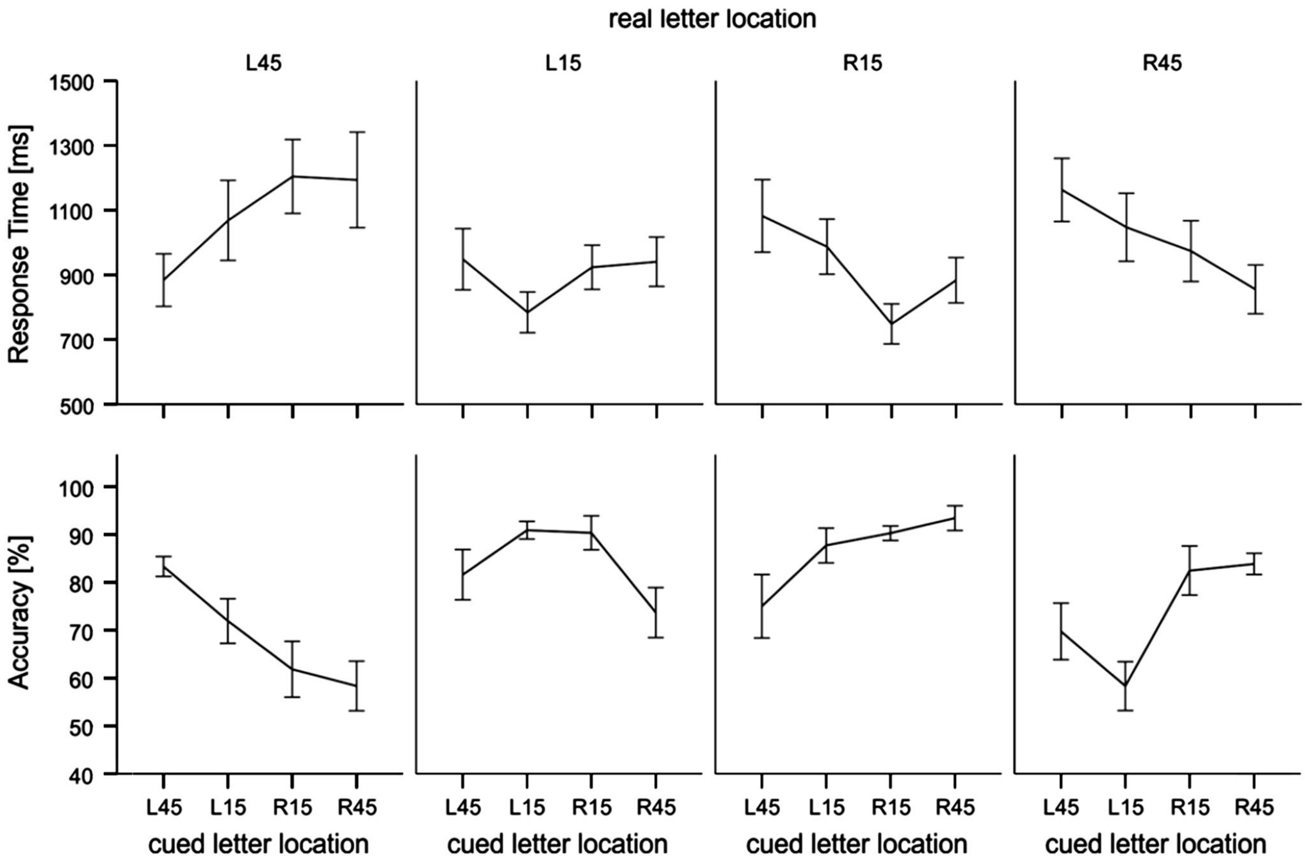

Fig. 5 Response times and accuracy of the discrimination task in Experiment 4. *Error bars* are standard errors

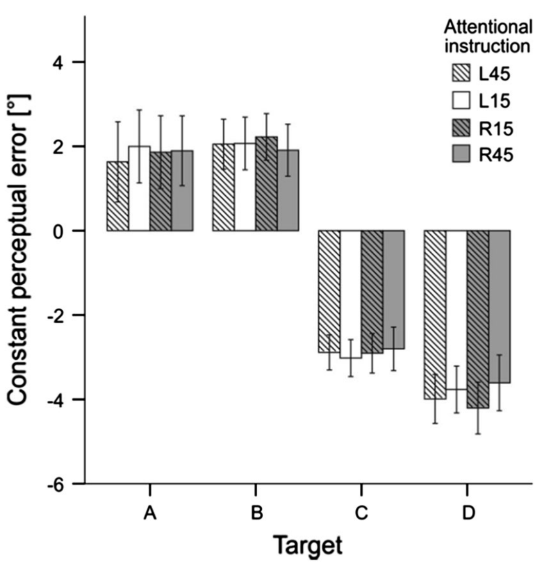

Fig. 6 Mean constant error as a function of attentional instruction in Experiment 4. *Error bars* are standard errors

analysis. Analogously to the results of the previous experiments, there was a rightward bias for the targets which were on the left side of the display and a leftward bias for the targets which were on the right side of the display.

We also tested whether position judgments differed between Experiment 1 and Experiment 4. For this purpose we ran an ANOVA with instructed attention/movement direction (left, right), instructed attention/movement deviation (15°, 45°) and target position as within subjects factors and experiment as a between subjects factor. This analysis revealed a significant main effect for experiment, $F(1,\ 37) = 7.3$, $p = .010$, $\eta_p^2 = .165$, and a significant interaction between instructed attention/movement direction and experiment, $F(1, 37) = 4.8$, $p = .035$, $\eta_p^2 = .115$. These results substantiate the conclusion that the effect of planned movement direction observed in the first experiment did not occur in Experiment 4.

Discussion

With Experiment 4 we aimed to test whether semantic information associated with alphanumerical cues and/or possible shifts of attention toward a spatial location may impact perceptual estimates in the current setup. The results of the present experiment, however, suggest that these factors are not sufficient to explain the results observed under conditions of movement planning in the first two experiments.

Participants were instructed to attend to a certain location in space indicated by a cue (and corresponding to the end points of required movements in Experiment 1 and Experiment 2) to manage the secondary perceptual discrimination task that replaced the hand movement performed in the previous experiments. Accordingly, the processes of semantic coding of the cue (e.g., as "left" and "right") and shifts of attentional focus can be assumed to be comparable across Experiment 1, Experiment 2 and Experiment 4. Whereas location cuing had an impact on discrimination performance, we did not observe any changes in judgments of target position dependent on cued location in Experiment 4. Thus, the effect found in the previous experiments appears to be closely related to the planning of a movement and seems to depend to a lesser extent on semantic coding of the cue or on mere shifts of attention.

Given that participants had enough time to perform saccadic eye movements during the adjustment procedure as well as before the appearance of the probe, the results of the discrimination task (effect of cue validity) may be due to overtshifts of attention. If so then the lack of a systematic impact of cue on position judgments may also indicate that motor planning of a saccade did not bias perception in the present setup, while planning of a hand movement did. This aspect, however, requires further research using control of ocular activity.

General discussion

The question of the present study was whether a variation of planned movement direction affects the perceived direction of visual stimuli. The results suggest this possibility. Participants prepared a movement according to a cue the end point of which deviated from a given target position to the left or to the right by 15 or 45° in Experiment 1 and 2. In Experiment 1, we observed a tendency to judge the given target position as being more left when movements to the right were planned and vice versa. This tendency was not reversed after the assignment of buttons to the direction of stimulus rotation during judgment was reversed ("Experiment 2"). This rules out that a response bias might explain the effect observed in Experiment 1. Moreover, the results of Experiment 3 revealed no impact of movement cue on perceptual estimates suggesting that the perception of target position was affected by movement planning processes rather than by the movement cue. Also, a possible activation of explicit semantic codes such as "left" and "right" by the cue and/or shifting of attention without movement preparation proved to be insufficient to explain the observed bias ("Experiment 4"). Thus, the results, as a whole, support the motor-planning hypothesis that suggests that several distinct variables specified during motor planning may be used as reference units for perception (see also introduction). Also, the results extend the previous research in that they indicate an impact of planned movement direction on the perception of target position.

Importantly, the direction of this motor-planning impact on perception was opposite to what we observed in previous studies. According to one line of thought, contrast effects arise if a feature integrated in or "occupied" by an action plan (e.g., spatial feature "left" during planning a movement to the left) is less available for a concurrent perceptual task (Hommel, 2004; Hommel & Müsseler, 2006; cf. also Schubö, Prinz, and Aschersleben, 2004; Zwickel et al., 2010a; for a similar approach emphasizing inhibition rather than occupation of shared representations). This may help to increase distinctiveness between features involved in action planning and those which are not (Hommel, 2004). Even though this idea can explain the current results, it appears unable to explain why using other motor and perceptual variables in closely related designs do produce assimilation phenomena (Kirsch et al., 2012; Kirsch & Kunde, 2012, 2013; cf. also Lindemann & Bekkering, 2009).

One explanation for this obvious discrepancy is that previous manipulations of movement characteristics, such as movement amplitude and movement force, went along with an overlap of motor and perceptual features (such as of movement costs and spatial target distance) on a metric dimension. In the present study, in contrast, the planned movement direction and the direction/position of stimuli overlapped on a categorical dimension. Evidence for such dissociation between categorical and metric representations in perceptual–motor tasks was recently reviewed by Thomaschke and colleagues (Thomaschke, 2012; Thomaschke et al., 2012). The authors argued that the majority of studies, in which perceptual–motor overlap can be considered to be a metric dimension, reported assimilation effects. In contrast, studies, in which perceptual-motor interactions are defined categorically, typically report contrast biases. The authors, however, went beyond this dissociation and further proposed that assimilation effects (linked to metric representations) result from the control of motor execution, whereas contrast effects (linked to categorical representations) result from action planning.

In line with this planning and control model (PCM), one can assume that the movement planning stage of the present study included categorical representations of movement direction (i.e., "left" and "right"). This would also explain why we did not find significant differences between the magnitude conditions (i.e., 15° and 45°) in the perceptual judgments of Experiment 1 and 2. Also, in a previous study (Kirsch et al., 2012) the magnitude variation of planned movement amplitude included more than two levels (similarly to the magnitude variation of movement direction of the present experiments). Unlike the present results, we observed that each magnitude level had a specific impact on perception in a predicted direction. This may be a hint that in our previous designs, movement planning included specification of rather metrical motor properties. The same may be true for other related studies reporting assimilation effects (e.g., Lindemann & Bekkering, 2009; cf. Thomaschke et al., 2012). Moreover, the specification of movement direction can be assumed to be more accessible to categorical coding than other parameters such as the amount of force (Kirsch & Kunde, 2012) or effector's end posture/position (Kirsch & Kunde, 2013).

Thus, if motor–perceptual contrast effects are associated with categorical coding and assimilation effects are due to metric variables, as suggested by Thomaschke and colleagues, but their assignment to motor planning and control stages is invalid, then the contrasting directions of effects observed in motor–perceptual tasks may be the result of a given task set (rather than of motor processing stage). This may possibly resolve why the PCM model cannot explain results from studies reporting contrast effects (e.g., Zwickel et al., 2010a) in which perceptual and motor tasks were performed concurrently (i.e., in which an effect of motor control processes on perception can be assumed) or from experiments in which motor planning causes assimilation effects (e.g., Gutteling et al., 2011). Also, some critical variables, such as "functional relation", "concurrency", or "ambiguity" identified by other authors (Zwickel & Prinz, 2012) may then be considered as factors related to a given task set, which may enable, facilitate or hinder a certain coding strategy.

Taking this idea for granted, it may appear puzzling why in a task that involves an obvious metric or spatial overlap of sensory and motor variables a contrast effect emerges (e.g., Schübo et al., 2004; Zwickel et al., 2010a). In such experiments, as in the present study, however, perceptual and motor tasks typically contained only a few categories. This per se may facilitate coding of sensory and motor variables in terms of given categories. Zwickel et al. (2010a), e.g., examined the nature of a contrast effect observed in situations in which visual stimuli and motor responses overlapped in time. Based on their results the authors argued that the critical representation is categorical.

Thus, because a metric feature can be transformed to categorical level, it depends on the perceiver's way of representing that feature, whether assimilation or contrast will be found. For example, Schubö et al. (2004) had participants perform hand movements while simultaneously encoding stimulus motion. A contrast effect was observed when the intertrial intervals (ITI) were short. This effect, however, turned into assimilation with longer ITIs. Given the time constraints with a short ITI, the content of the motor plan possibly relied on categorical representations of hand motion (e.g., intention to move "far" and "fast"). The representation of a simultaneously presented categorically compatible stimulus motion was then suppressed accordingly (see above). With longer ITI, however, participants had enough time to prepare a more detailed spatio-temporal movement pattern that produced interference on a metric dimension (i.e., an assimilation bias). In another study (Zwickel et al., 2010b), the direction of a hand movement repulsed a simultaneously presented stimulus motion when movement was unrestricted. When, however, the movement was unexpectedly blocked, an assimilation bias was observed. As suggested by the authors, planned movement direction may affect visual movement in assimilation-like manner "by default" initially "due to intrusion of features". As soon as motor and perceptual events have to be "shielded from each other" contrast effect emerges (p. 407). In other words, assimilation based on metrical features might be replaced by interference based on categorical features the more strategic processes come into play (cf. also Grosjean et al., 2009). Whether and to which extent this occurs seems to depend on the given task conditions. Some potentially critical variables here may relate to complexity and temporal aspects of the task. In the study of Schubö et al. (2004), e.g., the motor task was rather complex and required a substantial degree of resources prior to movement initiation. Accordingly, under time pressure categorical planning and control strategies may have predominantly been used. In the study of Zwickel et al. (2010b), in contrast, participants were faced with a simpler situation which did not possibly require strategic influences initially, promoting thus an assimilation effect in the blocked condition.

This would suggest, in line with our hypothesis (see Introduction), that the current content of the motor plan (or of the intention) determines the type of overlap of perceptual and motor features and, thus, the direction of interference under the given conditions (see also "Introduction"). A related idea has also been suggested by Wykowska et al. (2009). The authors observed that planning a grasping movement facilitated perception of object's size, while planning of pointing movements facilitated perception of luminance. Intentional weighting of perceptual dimensions which are relevant for an intended action has been assumed to explain these results. Accordingly, categorical planning of an action may "prime" or weigh other aspects of sensory information than a more detailed or metric specification of action parameters.

To further test these assumptions, one would have to directly compare conditions which enable either metric or categorical coding strategies during planning as well as during control stages of action. For example, the design of the present study may be extended by including more levels of possible movement directions. This may favor a more accurate (i.e., more metric) specification of movement parameters during planning, which in turn may promote an assimilation bias. It would also be interesting to see whether a stronger emphasizing or reducing of a categorical aspect of other tasks typically associated with a certain type of bias may produce an effect of opposite direction. Asking participants to judge the direction of apparent motion (instead of detecting the motion) in a task used by Lindemann & Bekkering (2009), e.g., may be assumed to force a categorical stimulus encoding and, thus, possibly to facilitate the emergence of a contrast effect. In a similar vein, a more metric variation of movement amplitude or direction in tasks used by Schubö et al. (2004) and Zwickel et al. (2010a) may possibly promote an assimilation bias. This may be done, e.g., by asking participants to execute movements with amplitudes or directions which deviate by a certain degree from a given simultaneously presented stimulus motion.

It would, of course, be presumptuous to expect that all the previous research on motor–visual priming and all aspects of the present data can be resolved along the suggested rationale given the complexity and diversity of sensorimotor processing. Accordingly, all conclusions should be considered with caution and the derived idea is certainly a question for future research. One possible caveat may be the lack of systematic biases in Experiment 4. When the critical representation is in fact related to such abstract categories as "left" and "right", then a contrast effect can also be expected if one has to be prepared to attend to the left or right side of the stimulus without movement planning. Thus, one possible conclusion from this could be that "left" and "right" are closely related to motor coordinates of the involved effector rather than to target stimulus or to other external cues.

To conclude, the present results suggest that planned movement direction may contribute to the perception of the object's position. In theory, such a phenomenon may be a result of perceptual–motor interactions on a rather abstract level of external or distal event codes shared by perception and action as suggested elsewhere (e.g., Hommel, Müsseler, Aschersleben and Prinz, 2001) or on a rather proximal level where early sensory information is enriched according to a motor parameter (e.g., Van der Heijden, Müsseler and Bridgeman, 1999; cf. also "Introduction"). In the present study, the critical representation appears to be rather abstract (or categorical) in nature. However, in face of an increasing number of studies reporting evidence for diverse types of perceptual–motor interactions, this seems to be valid only for a certain type of task context. To identify critical conditions, which promote the emergence of a specific type of motor influence on perception may be a promising research direction.

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