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Impact of action planning on spatial perception: Attention matters☆

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ABSTRACT

Previous research suggested that perception of spatial location is biased towards spatial goals of planned hand movements. In the present study I show that an analogous perceptual distortion can be observed if attention is paid to a spatial location in the absence of planning a hand movement. Participants judged the position of a target during preparation of a mouse movement, the end point of which could deviate from the target by a varying degree in Exp. 1. Judgments of target position were systematically affected by movement characteristics consistent with perceptual assimilation between the target and the planned movement goal. This effect was neither due to an impact of motor execution on judgments (Exp. 2) nor due to characteristics of the movement cues or of certain target positions (Exp. 3, Exp. 5A). When the task included deployment of attention to spatial positions (former movement goals) in preparation for a secondary perceptual task, an effect emerged that was comparable with the bias associated with movement planning (Exp. 4, Exp. 5B). These results indicate that visual distortions accompanying manipulations of variables related to action could be mediated by attentional mechanisms.

1. Introduction

How observers judge spatial aspects of their environment depends on the observers' current potentials and intentions to act (see e.g., Delevoye-Turrell, Bartolo, & Coello, 2010; Làdavas & Serino, 2008; Proffitt, 2008; Proffitt & Linkenauger, 2013; Witt, 2011; for reviews). For example, using tools that extend reaching range decreases the apparent distance to distant objects (e.g., Berti & Frassinetti, 2000; Farnè & Làdavas, 2000; Longo & Lourenco, 2006; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005), wearing a heavy backpack increases the apparent slope of a hill (Bhalla & Proffitt, 1999), and objects seem farther away when they are difficult rather than easy to grasp (Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009). These and similar effects are often explained by the old idea that motor variables serve as a reference (or "ruler") for early sensory information and thus, provide a basis for subjectively experienced perceptual events (cf. e.g., Proffitt & Linkenauger, 2013; Van der Heijden, Müsseler, & Bridgeman, 1999; Witt, 2011; see also Scheerer, 1984 and Viviani, 2002 for historical reviews). How such a "scaling" of sensory stimulation takes place however, is not well understood.

In the present paper, I explore the idea that visual attention contributes to the perceptual distortions that follow manipulations of action plans. It is known for long that planning a goal oriented movement incorporates the direction of visual attention to the endpoint of the movement. This has been inferred from facilitated processing of visual stimuli at target locations of planned hand or eye movements (see e.g., Deubel, Schneider, & Paprotta, 1998; Baldauf & Deubel, 2010 for a review). Planning to grasp rather than to reach an object enhances processing of object's orientation (Bekkering & Neggers, 2002; Gutteling, Kenemans, & Neggers, 2011). Also, planning a grasping movement facilitates perception of object's size, while planning of pointing movements facilitates perception of luminance (Wykowska & Schubö, 2012; Wykowska, Schubö, & Hommel, 2009). Obviously, thus, action planning processes are tightly coupled to visual attention. Perhaps, orienting attention is nothing else but the activity of sensorimotor circuits, in other words, it is a consequence of motor processes as suggested in premotor theory of attention (Rizzolatti, Riggio, & Sheliga, 1994).

Preliminary hints for a role of visual attention in action dependent plasticity comes from own previous work. The experimental task we used resembled those used in the research of attentional mechanisms (e.g., Deubel et al., 1998). Participants saw a cue that informed them about certain characteristics of an upcoming movement. Before movement execution they were asked to estimate certain distances. The larger the amplitude or force of the planned movement, the larger were judgments of the visual distance (Kirsch, Herbort, Butz, & Kunde, 2012; Kirsch & Kunde, 2013a). While these results suggested that

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motor planning affects visual perception, it was left unclear, which specific aspect of movement planning can be held responsible for these effects. In an attempt to isolate one of these variables we manipulated end locations of aiming movements with otherwise constant amplitudes (Kirsch & Kunde, 2013b). This did in fact affect distance judgments, suggesting that the anticipated movement goal distorts somehow the perceived location of objects that are part of the judged distance.

In the present study I went one step further, and tested whether shifts of spatial attention on their own are sufficient for perceptual distortions to occur. This is suggested by a couple of observations. For instance, the lines of Vernier stimuli are perceived as displaced after brief peripheral cues, which corresponds to a repulsion of the lines away from the attention-grabbing cues (Pratt & Turk-Browne, 2003; Suzuki & Cavanagh, 1997). Also, oval stimuli appear more or less stretched out depending on attentional cues (Fortenbaugh, Prinzmetal, & Robertson, 2011). Thus, there is good reason to speculate that attentional mechanisms involved in planning an action cause perceptual distortions.

Experiments 1–3 establish an experimental procedure to demonstrate robust influences of planned movement endpoints on the perceived position of movement-unrelated objects. Experiment 4 will then demonstrate that with essentially the same task perceptual perturbations emerge from orienting of attention alone without (obvious) necessity for planning a movement. Finally, Experiment 5 refutes a possible objection that the main findings are due to certain stimulus characteristics.

2. Experiment 1

The goal of Experiment 1 was to show that the anticipated endpoint of the planned movement biases perception of object's locations in an assimilation-like manner (end-point hypothesis, cf. Kirsch & Kunde, 2013b). That is, planning a movement to the left of a current target location should bias the perceived location of an object to the left. And conversely, the apparent target location should shift to the right when the endpoint of the planned movement deviates to the right of it. Also, the magnitude of the perceptual bias should increase with an increase in deviation between the target and the anticipated end position of the movement.

I combined a version of previously used planning-perception-execution paradigm (e.g., Kirsch & Kunde, 2013b) with a "position naming task" (Van der Heijden, Van der Geest, De Leeuw, Krikke, & Müsseler, 1999). In each trial participants judged the position of a target line shortly presented during preparation of a mouse movement (cf. Fig. 1). The planned end point of the movement could horizontally deviate from the position of the target line to the left and to the right by a varying degree. The main question of interest was whether and how target judgments are affected by the concurrently planned movements.

2.1. Methods

2.1.1. Participants

Twelve participants volunteered and provided written informed consent. They received payment for their participation. The sample included 9 females and 3 males with normal or corrected to normal vision. The mean age was 25 years ranging from 22 to 30 ($SD = 3$). All participants reported to be right handers.

2.1.2. Apparatus

Participants sat in front of a standard 19″ CRT monitor that was positioned approximately at eye-level at a viewing distance of about 65 cm. The monitor stood on a wooden superstructure that was positioned on a table. The participant's head was supported by a chin rest. The display had a resolution of 1024 (H) × 768 (V) pixels and a refresh rate of appr. 100 Hz. The background was white, the stimuli were black or colored (see below). A keyboard was placed at the left side in front of the participant on the table so that she could use it with the left hand. A computer mouse was placed at the right side of the participant so that she could use it with the right hand. The experiment was carried out in a low-illuminated room: only a faint

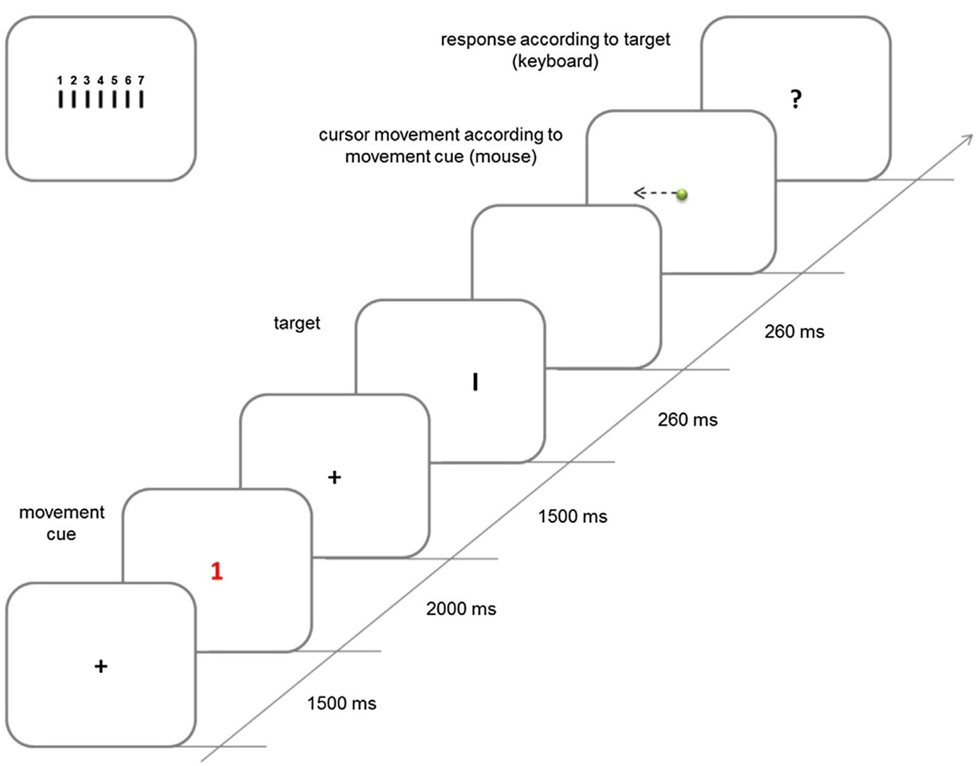

Fig. 1. Schematic illustration of the main trial events in Experiment 1. The assignment of numerical cues to the positions of the target line is shown in the left upper corner. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

light course was in between the table and the superstructure to allow the vision of the keyboard.

2.1.3. Stimuli and task

The main stimulus material included a black fixation cross (4×4 px), a black vertical target line (10×1 px), digits “1”, “2”, “3”, “5”, “6”, and “7” colored in red (~7 px in height) and a green dot indicating cursor's position (4 px in diameter).

The vertical line served as target and could appear at seven spatial positions (see Figure 1, top left part). The middle position was at the center of the display and corresponded with the position of the fixation cross. The remaining positions were equidistantly distributed to the left and to the right with inter-position spaces of 16 px (~0.5°). The total length of this array was thus, about 3° of visual angle.

Participants performed a dual task in which they were asked to look at the fixation cross if it was visible. No other restrictions of eye movements were given. In each trial the target line was randomly presented at one of seven positions and the participant had to estimate that position by entering a digit on a keyboard. The target positions were assigned to the digits so that an increase in digit magnitude was associated with a spatial shift from left to right (cf. Fig. 1, top left part).

Additionally, a second task was to move the mouse cursor (green dot) from the center of the display to one of the target positions (i.e., to one of the target lines) indicated by a red digit that was presented before at the center of the display. Thus, red digit served as movement cue indicating required endpoints for the mouse movements. The digit “4” assigned to the middle target position was skipped because no movement was possible in this case (i.e., cursor's start position coincided with its end position in this case, see below). The remaining six digit cues were used randomly and independently of the position of the target line. The dot movement was restricted to the x-axis, i.e., it could only be moved either to the right or to the left.

2.1.4. Procedure and design

The main trial procedure is shown in Fig. 1. Each trial was started by pressing the middle mouse button. One second after this button press the fixation cross appeared for 1500 ms. Then, the fixation cross was replaced by a digit indicating the required end position for cursor movement. After 2 s the cue was turned back into the fixation cross that remained visible for 1500 ms. Then a vertical target line was flashed for 260 ms. Following 260 ms a green dot appeared at the center of the display. The participant's task here was to move this dot towards a spatial position according to the movement cue by means of a mouse movement. After the movement was finished the participant had to press a mouse button. Then, a short text asking the participant to provide an estimate of the position of the target line appeared at the lower part of the display. After a digit was entered, the participant had to confirm her judgment by pressing the enter key of the keyboard. Before enter was pressed the judgment could be corrected by pressing the backspace key. After the judgment the fixation cross appeared together with a blue dot indicating the current cursor position. This was a signal to move the dot to the fixation cross and to press a mouse button.

There were two independent variables: *target location* and *cued location*. The target location refers to the spatial position of the vertical target line and contained seven levels (i.e., seven possible positions). The *cued location* is the location indicated by the movement cue. It ncluded all target locations apart from the middle.

The main experiment contained 3 blocks of 42 trials each. In each block each combination of target location and cued location was presented once in a randomized order. Before the start of the regular blocks participants were familiarized with the task by performing two practice blocks with 10 trials each which did not enter the analyses. The second practice block was identical to the regular blocks. In the first practice block, however, feedback was given about whether the judged target position was correct or not and how far the movement endpoint deviated from the cued position. Judgment feedback was shown as a short text after each estimate for 1500 ms (German terms for “correct” and “just missed”). As feedback of motor performance the movement endpoint was shown as a gray dot together with the cued position represented by a gray target line for 1500 ms. Moreover, in this first practice block the target was presented longer (400 ms). Also, at the beginning of each trial (i.e., before the first fixation cross) participants saw all target lines together with the according digits placed above the lines (see Fig. 1, top left part) for 2 s.

2.1.5. Data preprocessing

Trials in which perceptual error was larger than two (i.e., if judged target location deviated from the veridical target location by more than 2 locations), the error in motor reproduction was larger than 50 px and response times of the perceptual task exceeded 10 s werexcluded from analyses. In two participants, the proportion of these trials was very high (35% and 27%) indicating that they often did not follow the task instructions. The complete data of these participants were excluded. In the remaining participants 2.8% ($SD = 2.3$) of trails were excluded.

I also excluded the middle target condition from analyses in this and following experiments because the task was rather easy when the target line appeared at the location of the fixation cross (99%, 84%, 91%, 100% and 99% of responses were correct in Experiment 1, 2, 3, 4, and 5 respectively). Except for the middle target condition the mean absolute error rate in judgments of the target line in Experiment 1 was 23%.

2.2. Results

For each experimental condition the mean of the reported target positions served as a measure of perceived target position. Constant error was then defined as the deviation of the perceived position from the real target position: more positive values indicate a rightward tendency, whereas more negative values indicate a leftward bias.

Mean constant errors for the target and cue conditions are presented in Fig. 2. As shown, participants' response biases varied across the target as well as across the cued locations. The rightward bias observed for the left-most target decreased and turned into a leftward bias with a shift in target position from left to right. This increase in leftward bias seemed, however, to be not linear and to differ for the left and the right sides of the target array (cf. Fig. 2, left). More importantly, constant error was differently pronounced depending on the cued location: a change of the cued location from left to right was expressed in a relative increase of a rightward bias (cf. Fig. 2, right). An analysis of variance (ANOVA) including target and cued location as factors yielded significant main effects for both of these factors with $F(5, 45) = 5.7$, $p < .001$ and $F(5, 45) = 5.1$, $p = .001$ respectively. The interaction between both factors was not significant, $F(25, 225) = .8$, $p = .683$.

2.3. Discussion

The main result of Experiment 1 was that the implemented variation of planned movement significantly affected the judgments of target position. The characteristics of the observed effect were in line with the assumption that the anticipated or planned end position of the movement was the critical variable in the present experiment. According to the used rationale and setup, the impact of the movement cue on target judgments should vary depending on actual target position. For the left-most target, e.g., this means that only a rightward bias can be expected which should increase with a shift of the cue from left to right. For the right-most target, in contrast, only a leftward bias should occur which should also increase with cue-target distance. Since the predicted effect direction is comparable for these extreme target positions (as well as for other intermediate targets) a significant main effect of the cued location as well as the lack of a substantial interaction between the cued location and the target location is fully consistent with the end-point hypothesis.

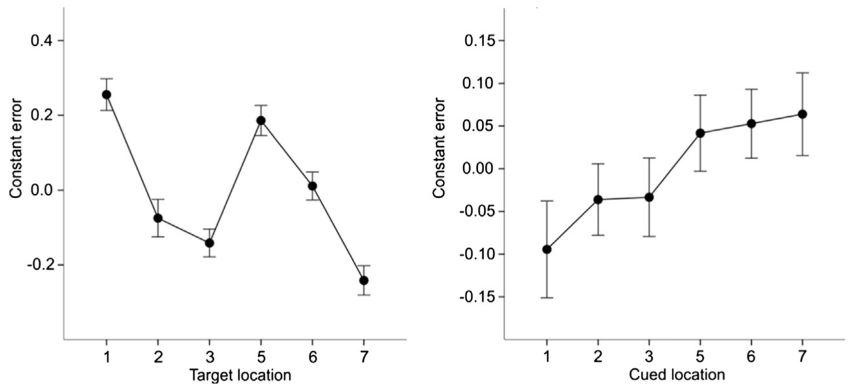

Fig. 2. Main results of Experiment 1. Error bars are standard errors.

I also observed that position judgments systematically varied depending on the absolute target position. The outer targets were considerably mislocalized towards the center of the display. This tendency decreased with a decrease in distance between the target and the center. This outcome resembles a "foveal bias" repeatedly observed in previous studies using similar setups (e.g., Kerzel, 2002; Müsseler et al., 1999; Van der Heijden, Van der Geest, De Leeuw, Krikke, & Müsseler, 1999): objects presented in the retinal periphery are perceived more foveal than they actually are. The pattern observed in the present experiment deviates to some extent from a "pure" foveal bias in that targets directly surrounding the middle target (i.e., the fixation cross) appear to be "repulsed" from the fovea rather than attracted by it. Due to the main focus on the role of movement preparation I do not consider this aspect of the results further.

3. Experiment 2

In line with our previous studies, the results of Experiment 1 indicated that planning a movement may distort perception of an object. One caveat of Experiment 1, however, may be that the judgment of target position was affected by some aspects of the action execution (i.e., of mouse movement) whereas target's perception was unaffected. To explore this possibility I slightly changed the trial procedure by asking the participants to report perceived target location before executing the movement. A pattern of results that is similar to that of Experiment 1 would substantiate the conclusion that processes going on during movement preparation have a measurable impact on perception of visual objects in the present setup.

3.1. Methods

3.1.1. Participants

Twelve participants volunteered and provided written informed consent. They received payment for their participation. The sample included 9 females and 3 males with normal or corrected to normal vision. The mean age was 28 years ranging from 20 to 39 ($SD = 7$). One of the participants reported to be left hander.

3.1.2. Apparatus, stimuli and task

The apparatus, stimuli and the general task were the same as in Experiment 1.

3.1.3. Procedure and design

The trial procedure and the design were the same as in Experiment 1 with only one exception: the estimate of the target position was now required before the mouse movement (cf. two backmost events in Fig. 1, which were interchanged in Experiment 2).

3.1.4. Data preprocessing

Data preprocessing was performed in the same way as in Experiment 1. One participant seemed to misunderstand the task instructions (56% of trials had to be excluded based on the used preprocessing criteria). Her data was not included in the analyses. The proportion of excluded trials for the other participants was 4.0% ($SD = 4.1$) on average. Except for the middle target condition the mean absolute error rate in judgments of the target line was 29%.

3.2. Results

Mean constant errors for each target and each cue condition are shown in Fig. 3. As in Experiment 1, a change of the cued location from left to right was associated with in a relative increase of a rightward bias (cf. Fig. 3, right). The variation of the target location was also similarly pronounced as compared with the results of Experiment 1: a shift of target location from left to right was associated with a shift from a rightward bias to a leftward bias, obviously following a two-step function. An ANOVA performed on the constant error values revealed significant main effects for target and cued location with $F(5, 50) = 5.6$, $p < .001$ and $F(5, 50) = 3.4$, $p = .010$. The interaction between both factors was not significant, $F(25, 250) = .8$, $p = .725$.

3.3. Discussion

The main results of Experiment 2 were straightforward. The effect of cued location observed in Experiment 1 cannot be explained by an impact of movement execution on judgments of target location. Despite the fact that the perceptual task preceded the motor execution in Experiment 2, an effect of cued location on judgments of target location was still evident and was similarly pronounced as in Experiment 1.

On average, however, participants judged the locations to be more left than in Experiment 1. I assume that this overall leftward bias might be a result of a poorer calibration of the array of positions that had to be retrieved during each judgment. Appearance of the cursor at the middle position of the array before judgment in Experiment 1 (cf. Fig. 1) might have been useful to calibrate the retrieved array at the center of the screen. In Experiment 2, in contrast, there was no such a possibility after target presentation. As a result, a systematic bias may arise. This overall bias, however, does not substantially limit the drawn conclusions relating to the impact of movement cue.

4. Experiment 3

With Experiment 3 I aimed to test whether the numerical magnitude of the cue may produce the observed effect rather than some processes

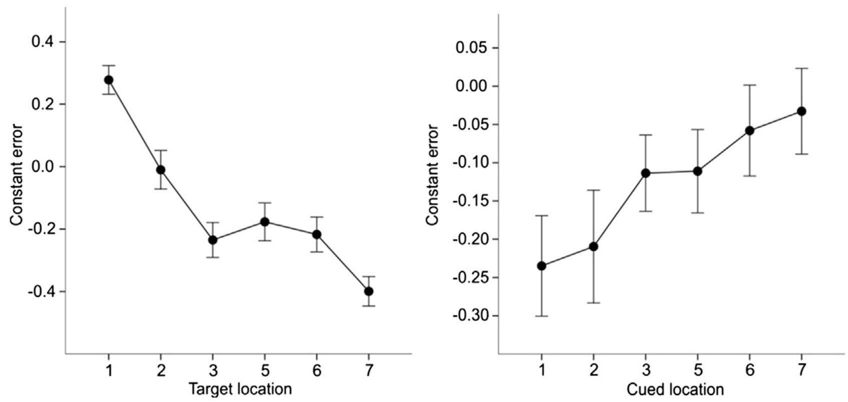

Fig. 3. Main results of Experiment 2. Error bars are standard errors.

associated with movement preparation (cf. Kirsch et al., 2012). Such a relation might be referred to a spatial correspondence between the position of a number on a left-to-right oriented "mental number line" and the position of response (Dehaene, Bossini, & Giraux, 1993; see e.g., Gevers & Lammertyn, 2005 for a review).

Thus, a rather small number can bias the perceptual judgment to the left whereas a rather large number can bias to the right. Accordingly, contrary to the assumed origin of the observed effect, the results of Experiment 1 and of Experiment 2 may entirely be unrelated to motor planning. To test for this possibility I modified the setup of Experiment 2 by inverting the assignment of the digits to the target lines in Experiment 3. If the effect observed in the previous experiments is due to numerical cue characteristics, then it should similarly be pronounced in Experiment 3. Otherwise, the direction of the effect should be reversed due to an inverted assignment of the digits to the spatial positions.

4.1. Methods

4.1.1. Participants

Thirteen participants volunteered and provided written informed consent. They received course credit for their participation. The sample included 12 females and one male with normal or corrected to normal vision. The mean age was 21 years ranging from 19 to 26 ($SD = 2$). Two of the participants reported to be left handers.

4.1.2. Apparatus, stimuli and task, procedure and design

All details of the apparatus, stimuli, task, procedure and design were the same as in Experiment 2 except for the assignment of the digits to the spatial positions of the target line that was now inverted. That is, the appearance of the target line at the left-most position required the typing of the number "7", whereas the right-most target position was associated with the number "1" etc.

4.1.3. Data preprocessing

Data preprocessing was performed in the same way as in the previous experiments. Two participants were excluded (25% and 17% of trials were erroneous based on the used preprocessing criteria). The proportion of excluded trials for the other participants was 2.5% ($SD = 1.7$). Except for the middle target condition the mean absolute error rate in judgments of the target line was 24%.

4.2. Results

Fig. 4 shows mean constant error values[1] for the target and cue locations. In contrast to the results of Exp. 1 and Exp. 2, the target line was judged to be successively more left with an increase in digit magnitude. Also, a shift of target location from left to right was associated with a non-linear shift from a leftward bias to a rightward bias. These observations are substantiated by the results of an ANOVA including target location and digit magnitude as factors: main effects were significant with $F(5, 50) = 4.0$, $p = .004$ and $F(5, 50) = 4.5$, $p = .002$ respectively (other $p = .442$). Thus, reversing the assignment of the digits to the spatial locations of the target lines in Exp. 3 seemed to mirror the results of the previous experiments around the middle of the target range.

4.3. Discussion

If participant's judgment errors are considered in respect to the magnitude of the number used as movement cue, then the effect of the cue on the results of Experiment 3 is of an opposite direction as compared with previous experiments. Thus, the characteristics of the cue cannot account for participant's judgment errors depending on movement cue.

It is worth mentioning that in contrast to the results of Experiment 1 and of Experiment 2 participants showed a rightward bias on average in Experiment 3. This result might indicate a tendency towards the mental origin of the to be retrieved array that can be assumed to be on the left side of the screen in Experiment 2 but on the right side in Experiment 3 (cf. also the Discussion section of Experiment 2).

5. Experiment 4

The previous results indicated changes in target's perception depending on planning a mouse movement. Planning a movement is usually accompanied by a shift of attention towards a movement goal (e.g., Deubel et al., 1998; see also the Introduction section). Thus, one potential variable which is closely associated with the observed perceptual plasticity may be the actual focus of attention. Considering the current experimental setup one may argue that the appearance of movement cue is followed by a shift of attention towards the cued location (i.e., towards a potential movement goal). Given that attentional cues may cause perceptual distortions (Fortenbaugh et al., 2011; Pratt & Turk-Browne, 2003; Suzuki & Cavanagh, 1997, see also the Introduction section) the same target position may be perceived differently depending on cued location.

To test for this possibility I replaced the movement phase of the previous experiments by a perceptual discrimination task. After each position judgment participants had to make a decision about whether the position of an additionally presented line corresponds to the position indicated by the numerical cue. Thus, participants had to attend to the spatial position indicated by the cue before or during the primary perceptual task in order to handle the secondary perceptual task (cf., e.g., Exp. 1 in Posner, Snyder, & Davidson, 1980).

[1] Constant error was defined as the deviation of the real from the perceived target position in order to ensure that positive values still reflect a rightwards bias.

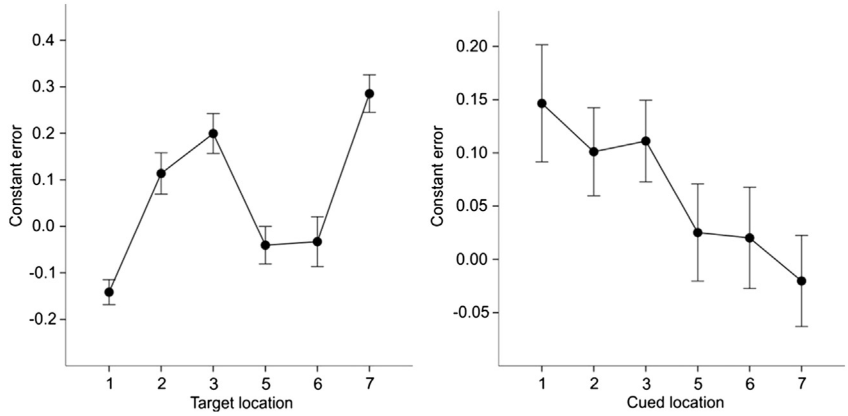

Fig. 4. Main results of Experiment 3. Error bars are standard errors.

The rationale was as follows. If an effect is detectible in Experiment 4 that is comparable with the effects observed in the previous experiments, then the critical variable responsible for the impact of motor planning on perception would be related to processes associated with the distribution of spatial attention. Otherwise, the critical level of motor-perceptual interactions would be more subtle.

5.1. Methods

5.1.1. Participants

Twelve participants (two males) volunteered and provided written informed consent. They were paid for their participation. All participants reported to be right handers with normal or corrected to normal vision. The mean age was 29 years ranging from 21 to 54 ($SD = 8$).

5.1.2. Apparatus, stimuli and task, procedure and design

The procedure of Experiment 2 was modified so that 1 s after the judgment of target position, an additional line (cue probe) that was red in color and same in size as the target line was presented together with the fixation cross (black) for 1000 ms (cf. Fig. 5). The participants' task was to decide per mouse button whether the spatial position of the cue probe corresponds with the position indicated by the numerical cue presented before. The assignment of the mouse buttons (left/right) to the categories of response (yes/no) was counterbalanced across participants. The probability that the position of cue probe was correct was about 50% on average. The probe could also appear at one of the other possible positions (at each with appr. equal probability).

In the initial practice block participants received feedback about their performance in this secondary task. All other details of the procedure, design, stimuli and task were the same as in Experiment 2.

5.1.3. Data preprocessing

Analogously to the previous experiments, trials in which judged target location deviated from the veridical target location by more than 2 locations, trials in which response times of the primary perceptual task exceeded 10 s, and trials with incorrect responses in the secondary perceptual task were excluded from analyses. One participant was not able to follow the task instructions as indicated by 71% of trials which had to be excluded based on the used criteria. Her data was not included in the analyses. The proportion of excluded trials for other participants was 14% ($SD = 9$) on average. Except for the middle target condition the mean absolute error rate in judgments of the target line in the primary task was 23%.

5.2. Results

As shown in Fig. 6, the variations of the cue as well as of the target location again affected perceptual judgments. Moreover, the trends were in line with the previous results. A shift of the cued location from left to right was accompanied by a rightward shift of the constant error (cf. Fig. 6, right). Also, a shift of the target location from left to right was expressed in a biphasic leftward shift of the constant error (cf. Fig. 6, left). A statistical analysis (ANOVA) performed on constant errors[2] revealed significant main effects of cued location, $F(5, 50) = 6.3$, $p < .001$, and of target location, $F(5, 50) = 5.5$, $p < .001$. An interaction between both factors was not significant, $F(25, 250) = 1.3$, $p = .169$.

5.3. Discussion

Replacing the mouse movement by a secondary perceptual task did not change the results of the previous experiments substantially. This suggests that the perceptual plasticity observed with the present and similar setups is closely linked to spatial attention mechanisms. This conclusion is also in line with the results of a recent study showing that the "foveal bias" (cf. Exp. 1) is susceptible to variations of attention: it increased under conditions of distributed attention and disappeared under conditions of focused attention (Bocianski, Müsseler, & Erlhagen, 2010).

6. Experiment 5

The main purpose of Experiment 5 was to test whether the impact of cued locations observed in the previous experiments might exclusively be explained by differences between the leftmost and the rightmost target locations at which only a rightward or only a leftward bias could emerge. For this purpose, Experiment 2 and Experiment 4 were run again using two additional target locations which were placed to both sides of the original target array and which were then discarded from analyses. If the previous results are mainly due to outer target locations then an impact of the cued location should not be observed in Experiment 5.

[2] The data of two participants was not complete due to a total of three missing values. These values were replaced by the mean of the whole sample in the respective conditions (target 1 & cue 6, target 2 & cue 2, target 7 & cue 2). Note, excluding these participants from the analyses did not alter the results substantially: a main effects of cued location and of target location were still significant with $F(5, 40) = 5.5$, $p = .001$, and $F(5, 40) = 4.8$, $p = .002$ respectively.

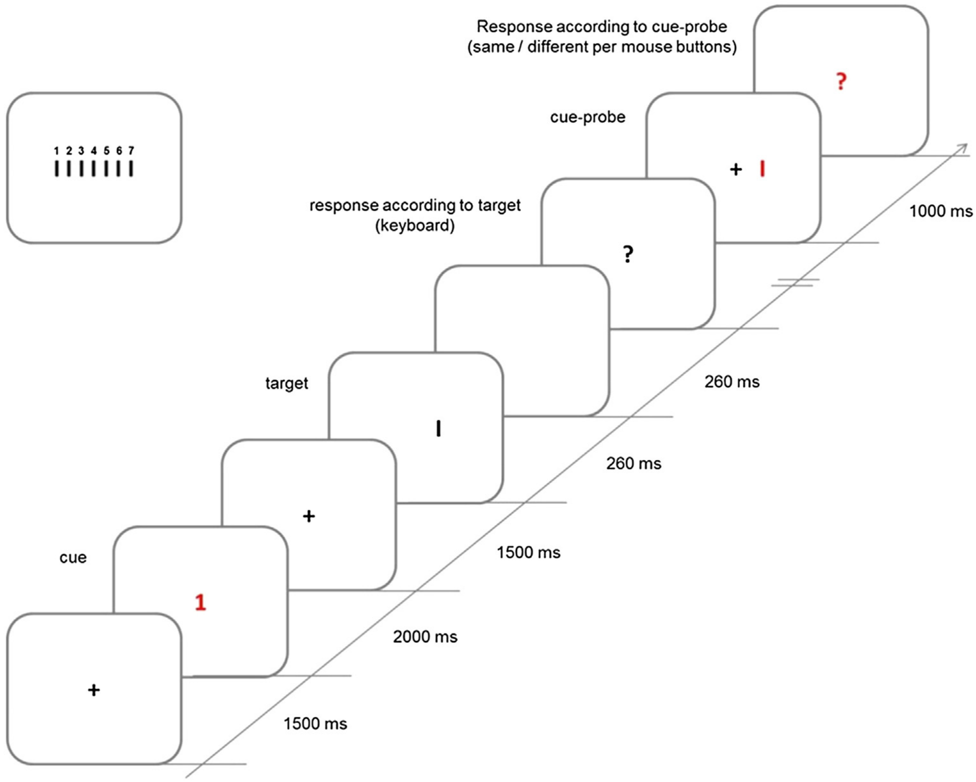

Fig. 5. Schematic illustration of the main trial events in Experiment 4. The assignment of numerical cues to the positions of the target line is shown in the left upper corner. Note, one blank display following "response according to target" was skipped. It appeared immediately after the target judgment was confirmed and remained visible for 1 s until the cue probe.

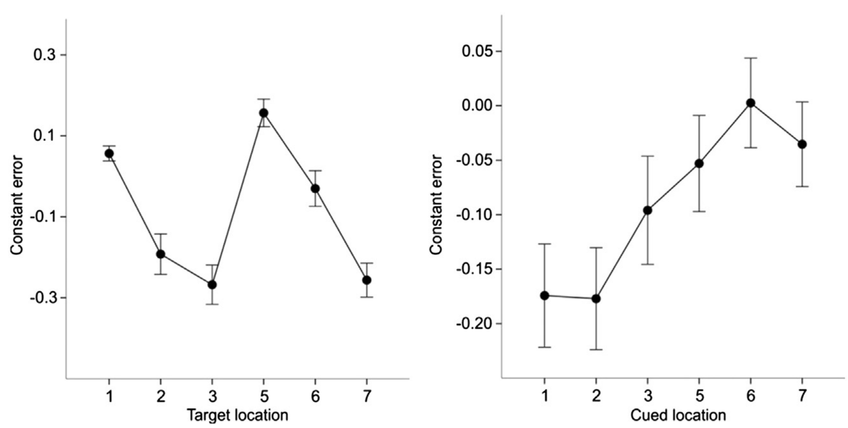

Fig. 6. Results of the primary perceptual task in Experiment 4. Error bars are standard errors.

6.1. Methods

6.1.1. Participants

Twenty-four participants (three males) participated in Experiment 5. They provided written informed consent and received course credit for their participation. All participants apart from two reported to be right handers. They had normal[3] or corrected to normal vision. The mean age was 21 years ranging from 18 to 35 ($SD = 4$). Twelve participants participated in Experiment 5A and twelve participants participated in Experiment 5B.

[3] One participant reported to have a very slight impairment that, however, according to the participant does not need to be corrected. Excluding this participant from the analyses did not alter the results substantially.

6.1.2. Apparatus, stimuli and task, procedure and design

The setup of Experiment 5A was very similar to the setup of Experiment 2 and the setup of Experiment 5B was very similar to the setup of Experiment 4. The main change implemented in Experiment 5 was the using of 9 instead of 7 target locations. One additional target line was positioned left of the previously leftmost target line, another target line was added to the right side of the array (on the right side of the previously rightmost target). The inter-position spaces of 16 px (~0.5°) were preserved. The assignment of the digits to the lines changed insofar as the middle target was now labeled as "5" (the leftmost target was "1" and the rightmost target was "9"). Each

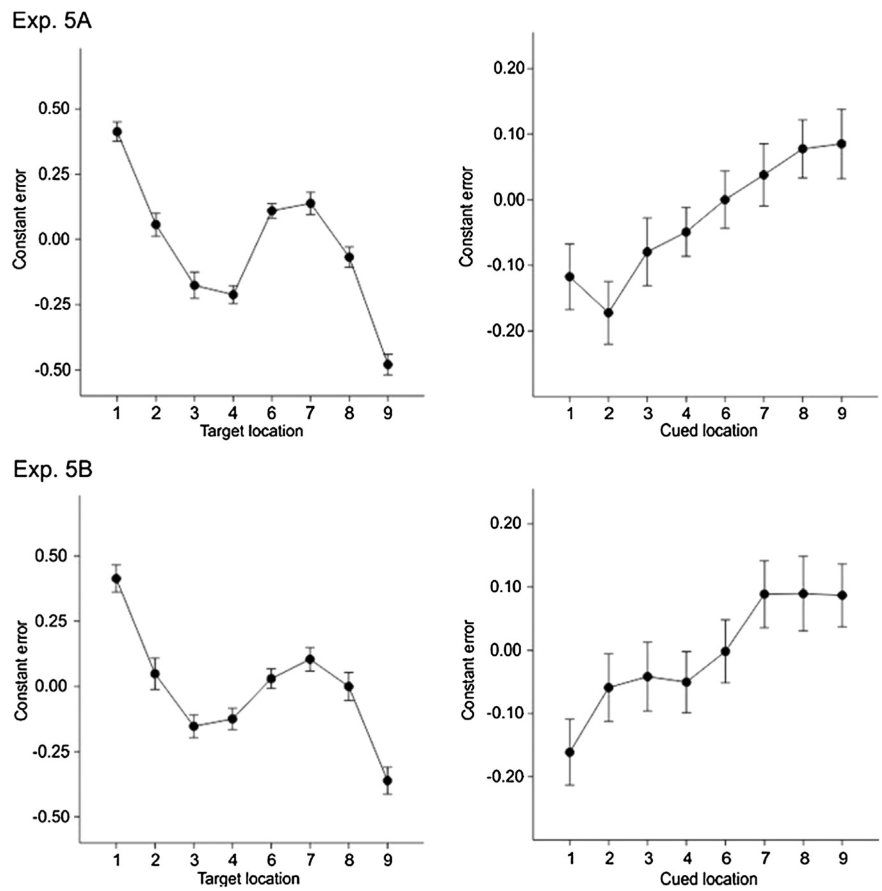

Fig. 7. Constant judgment error in Experiment 5. Error bars are standard errors.

experiment (i.e. Exp. 5A and Exp. 5B) was divided into 6 blocks of trials. Each block included 36 trials.

A minor change was related to the placement of the keyboard that was positioned on the wooden superstructure now. Also, the light previously used to illuminate the keyboard was not used in Experiment 5.

In this experiment I also explicitly noted during the practice blocks that the center of the target array (i.e., the position "5") is at the place of the fixation cross to facilitate the calibration of the array for the judgment (cf. also the Discussion section of Exp. 2).

6.1.3. Data preprocessing

Data preprocessing of Experiment 5A and Experiment 5B was performed in the same way as in Experiment 2 and in Experiment 4 respectively. One participant was excluded from analyses of Experiment 5A (18% of trials were erroneous based on the used preprocessing criteria). The proportion of trials for the other participants of Experiment 5A was 3.2% ($SD = 3.6$). Except for the middle target condition the mean absolute error rate in judgments of the target line was 31%. Similar to the previous experiments, Experiment 5B was more difficult than Experiment 5A as indicated by a larger mean proportion of excluded trials (15.5%, $SD = 9.6$). The mean absolute error rate in the judgments of the target line in the primary task (except for the middle target condition) was 32%.

6.2. Results

Fig. 7 shows mean constant error values observed in Experiment 5 averaged according to target locations (left) and cued locations (right). The characteristics of these values are very similar to those observed in the previous experiments. To ensure that the previous results were not exclusively due to outer positions, positions "1" and "9" were discarded from further analyses. As in the previous experiments, the middle position was also not included in the analyses.

An ANOVAs performed on the constant error values of Experiment 5A revealed significant main effects for target and cued location with $F(5, 50) = 4.2$, $p = .003$, and $F(5, 50) = 5.8$, $p < .001$. An interaction between both factors was not significant, $F(25, 250) = .8$, $p = .754$. An ANOVA performed on the constant error values of Experiment 5B[4] revealed a significant main effects for cued location with $F(5, 55) = 4.6$, $p = .001$. Neither a main effect of target location nor an interaction between both factors was significant, $F(5, 55) = 1.4$, $p = .244$ and $F(25, 275) = 1.2$, $p = .208$. Thus, the impact of cued location was present in Experiment 5 when the leftmost and rightmost target positions were excluded from analyses.

Given that the constant error varied to some extent depending on cued location between Experiment 5A and Experiment 5B I also tested whether these apparent differences are substantial. For this purpose, an ANOVA was run including experiment as a between subjects factor. The factor experiment proved to have no significant influence in this analysis ($ps > .251$) indicating that judgment behavior was similar in spite of task differences associated with the type of location cuing.

Moreover, additional analyses (ANOVAs) were performed in which the outer target locations were excluded but the outer cued locations were preserved. This was done to allow participants to show biases

[4] Similar to Experiment 4, the data of three participants had missing values. These values were replaced by the mean of the whole sample in the respective condition. Note that excluding these participants from the analyses did not alter the presented results substantially.

towards both sides even at the leftmost and the rightmost target locations. The results here were analogous to those described above.

6.3. Discussion

Experiment 5 examined whether the impact of the movement and attentional cues on judgment behavior observed in the previous experiments might be explained by differences between the leftmost and the rightmost stimulus locations. The results were clear-cut. The effect of cued location was still evident after discarding the outer positions from analyses indicating that the effect observed in the present and the previous experiments was not exclusively due to the leftmost and the rightmost stimulus locations.

Moreover, participants' judgment behavior did not differ substantially between Experiment 5A and Experiment 5B. This suggests that the attentional manipulation (Exp. 5B) affected target perception similarly as the manipulation of the planned mouse movement (Exp. 5A).

It is also worth noting that there was no obvious overall bias towards the left or the right side of the display as in some of the previous experiments. I assume that this outcome was a result of an explicit pointing the participants to the fact that the middle of the target array (i.e., position "5") is at the position of the fixation cross (see the Methods section). This might have been facilitated the calibration of the retrieved target array at the center of the screen during judgments (see also the Discussion section of Exp. 2).

7. General discussion

In the present study I examined how planning a movement affects perception of a target location. Experiment 1 revealed that when the end position of the planned movement deviates to the right of the actual target the perceived target location shifts to the right and conversely, when the movement deviates to the left the apparent target location is biased to the left. Neither an effect of movement execution on target judgment nor the characteristics of the cue or of certain target positions proved sufficient to explain this result as indicated by Experiment 2, Experiment 3 and by Experiment 5A. When the task included a secondary perceptual task requiring deployment of attention to spatial positions previously used as movement goals, basically the same effect emerged (Experiment 4, Experiment 5B). These results suggest that the observed visual plasticity emerged as a consequence of shifting attention to varying spatial locations.

The present results and the recent progress in attention research may provide a new insight in how motor variables affect visual perception. In particular, if the mosaic of receptive fields can be altered by modulation of spatial attention as suggested[5] (cf. Anton-Erxleben & Carrasco, 2013), then the spatial resolution across the visual field can be expected to vary depending on several factors affecting attentional distribution. One such factor (perhaps the most critical) is certainly related to action planning. Thus, an impact of motor variables on perception can be achieved through modulation of spatial attention adjusting spatial resolution of the visual system according to planned actions. In other words, the state of the visual receptive fields (i.e., those shapes and positions) during sensory stimulation might be responsible for actions' effects on perception.

This conclusion is preliminary and should be considered with caution. Particularly, I did not measure ocular activity and thus, can only indirectly assess its impact. For example, assuming that the initial numerical cue triggered a saccade towards the cued position and that this eye position was maintained until the target was presented the observed modulation of reported target position depending on cued location may reflect a foveal bias mentioned previously (i.e., a tendency to mislocalize towards the fovea). If this would be the case, the observed effect would not be related to rather covert shifts of attention as assumed, but to the eye position during target presentation. There are, however, at least two arguments which speak against this possibility. First, after the cue disappeared, a fixation cross was presented for 1.5 s. It appears rather improbable that despite the presence of the fixation cross and the instruction to fixate this cross participants systematically continued to fixate the cued position. Second, in all experiments, an effect of target position resembled a typical "foveal bias" indicating that targets were in fact presented in the retinal periphery rather than in the fovea (at least if extreme target positions are considered). Admittedly, however, more research is needed here to examine the role of eye movements in related setups.

To sum up, the present results delineate that planning an action may distort the visual space through attentional modulation. This seems to provide a new insight how motor and perceptual processes interact and calls for closer look at spatial attention and ocular activity in future studies.

[5] Perceptual alterations observed as a consequence of attentional reorientations were referred to changes of the size (e.g., shrinking and expansion) and position (e.g., shift towards the attended stimulus) of receptive fields.

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