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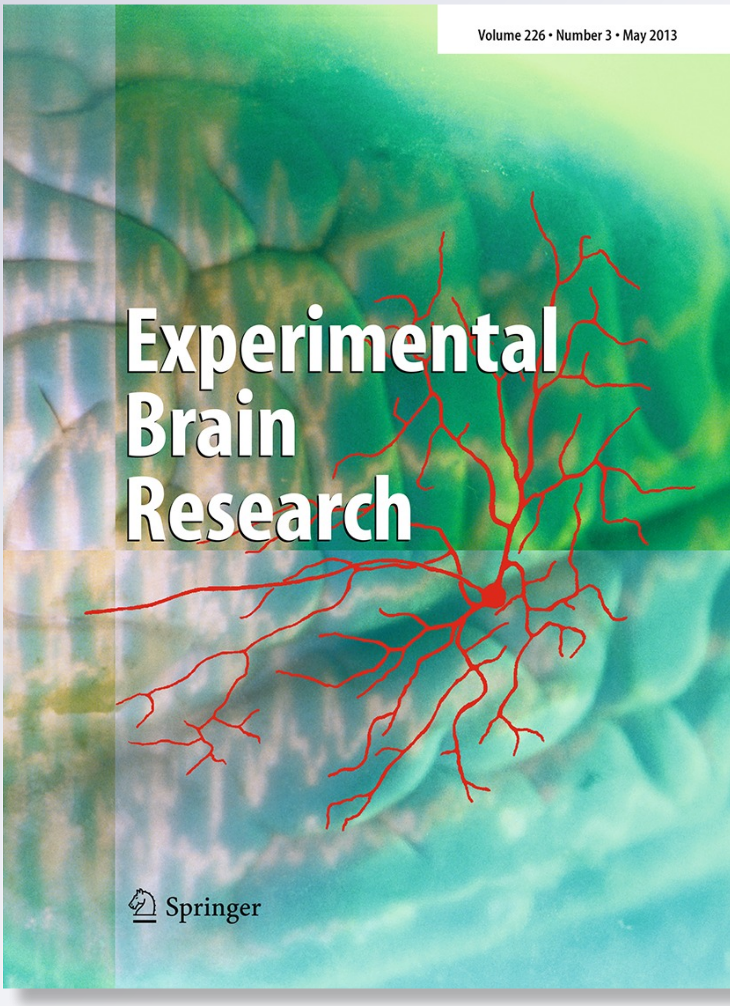

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RESEARCH ARTICLE

Moving further moves things further away in visual perception: position-based movement planning affects distance judgments

Wladimir Kirsch · Wilfried Kunde

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Abstract We examined how different characteristics of planned hand movements affect visual perception of distances in reachable space. Participants planned hand movements of certain amplitude. Before execution of the movement, certain visual distances had to be judged. Distances were judged as larger the larger the amplitude of the concurrently prepared hand movements was. On top of that, with constant movement amplitude, distances were judged as larger, the further away the start point of the planned movement was located from the body. These results indicate that distinct variables specified during motor planning, such as effector's final position, are linked to the visual perception of environmental characteristics.

Keywords Distance perception · Hand movements · Perception–action coupling · Embodied cognition

Introduction

Common views of information processing suggest that what we perceive determines what we will do (e.g., linear stage theory, Sanders 1980). Yet, there is also compelling evidence for influences in the opposite direction: What we will do determines what (and how) we perceive (see e.g., Proffitt 2008 for a review). For instance, a hill can be perceived as steeper by wearing a heavy backpack (Bhalla and Proffitt 1999). In sport, the perception of goals can be modulated by athlete's momentary form (Lee et al. 2012; Witt and Dorsch 2009; Witt et al. 2008).

The perception of near space is also biased by certain motor variables. Several paradigms revealed plasticity phenomena related to tool use. For example, an egocentric distance to a target object is perceived smaller when holding a tool extending reaching ability (Berti and Frassinetti 2000; Farnè and Làdavas 2000; Longo and Lourenco 2006; Witt 2011; Witt and Proffitt 2008; Witt et al. 2005). Witt et al. (2005), for example, asked participants to estimate a target distance and then to perform a pointing movement toward the target. Distances were judged to be shorter when pointing with a conductor's baton than when pointing with the finger. In another paradigm, participants were asked to bisect lines located in different distances (e.g., Longo and Lourenco 2006). In near space, a tendency to judge the midpoint of the line to be left of its real position was usually observed. With growing distance between line and participant, this bias shifted from left to right when judgments were made by means of a laser pointer. When sticks were used during judgments, however, no left to right shift with distance occurred.

These and similar results indicate that purposes and abilities of acting in a particular situation modulate subjective experience of environment. However, the exact mechanisms underlying the observed action–perception interactions are not well understood. One basic idea holds that physical features of the environment such as extent are (re)scaled by metrics derived from perceiver's body before they enter subjective experience (cf. e.g., Witt 2011; Witt et al. 2010). In other words, perception is assumed to be determined by initial optical information which is "interpreted" by a motor variable that serves as a kind of "perceptual ruler" (cf. Linkenauger et al. 2009; Proffitt and Linkenauger 2013).

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Possible changes within or across these motor reference scales may then give rise to perceptual plasticity phenomena. The compression of a subjective target distance by using a tool in previous studies (see above), for example, can be explained by the stretching of the "ruler" (Linkenauger et al. 2009). The critical motor variable here was assumed to be "reaching ability" (or arm length) which is extended by using a tool. As a consequence, the apparent distance to the target object decreases.

Besides the type of motor action (tool use, wearing a backpack, successful sport action), much more subtle characteristics of essentially the same motor actions have an impact on perception as well. In one study, for example, the task was to bisect lines presented in varying distances by a laser pointer (Lourenco and Longo 2009). At near distances, a tendency to judge the midpoint of the line as being more rightward was observed when participants were wearing a weight on the wrist during the estimation procedure as compared with a control condition. This result was assumed to reflect overestimation of a given distance following increasing effort related to the involved effector. Linkenauger et al. (2009) measured distances to objects that had an orientation that either was or was not beneficial for grasping them. The authors observed that right-handed participants judged distances larger when objects were difficult rather than easy to grasp. These findings may indicate that specific values of variable parameters (e.g., amplitude, force) of a certain motor plan (pointing or reaching) bias perception. In previous studies, we extended these findings showing that when participants are asked to prepare a pointing movement of their right arm, visual distances in reaching space are perceived as longer the larger the amplitude and the larger the necessary force of the planned movement (Kirsch et al. 2012; Kirsch and Kunde in press).

While these results suggest that certain parameters of planned motor actions affect perception, the specific parameters that do so, and how they do so, remain to be scrutinized. Describing motor action in terms of "parameters" is essentially a technical description of physical aspects of the movement, but these need not necessarily map to the psychological factors that underlie the influences of actions on perception. One might argue, for example, that movements with larger amplitudes and larger forces are both more effortful and that perceived effort is the true latent variable (or "perceptual ruler") that affects visual distance perception. One observation that points in this direction is that amplitude and force affect perception in interactive rather than independent manner (cf. Kirsch and Kunde, in press for this issue). In any case, a more detailed investigation of action characteristics that affect perception is needed before ultimate conclusions about underlying causal variables can be drawn.

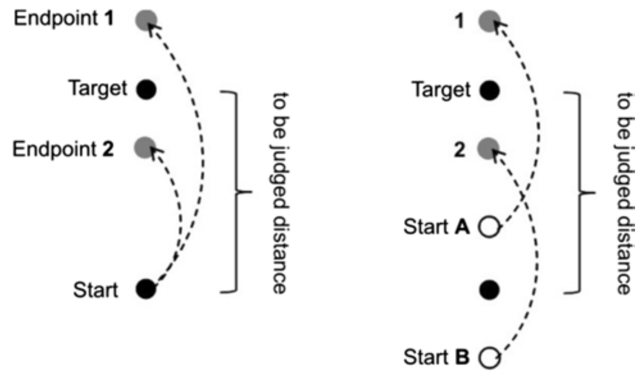


Fig. 1 Hypothetical trajectories and endpoint locations for two movements aimed to undershoot and to overshoot a given target. If both movements are made from the same start position (*left*), their extent differs additionally to their endpoint locations. A variation of start location shown on the *right side* can be used to equal the amplitudes of both movements and thus, to restrict possible statements about perceptual modulation to the variation of endpoint locations

The present study is meant as a step in this direction. It aims at disambiguating the factors inherent in manipulations of movement amplitude on visual perception. To illustrate this ambiguity please consider Fig. 1 (left part). If participants are asked to under- or to overshoot a given target by a certain degree as in our prior studies, the amplitude of an overshooting movement is larger than the amplitude of the undershooting movement. Simultaneously, however, the endpoint locations (as well as movement times) also differ for both movements. Accordingly, if an effect of planning a movement that varies regarding its amplitude on perception can be observed, then this effect may also be due to variations of amplitudes, endpoint locations, or both. Here, we asked whether planned movement endpoint location is a movement characteristic that can affect distance perception in itself.

Separating influences of movement endpoints from movement amplitudes might seem like hair-splitting, but there is in fact lot of evidence showing that movements can be planned and controlled in terms of both, amplitudes (e.g., Bock and Eckmiller 1986; Gordon et al. 1994) as well as in terms of locations (e.g., Heuer 2002; Polit and Bizzi 1979). Moreover, information relating to amplitudes and endpoint locations may be used in parallel during planning, control, and memory of movements (e.g., Heuer 1981; Heuer and Klein 2006; Walsh et al. 1979). Thus, the modulation of perceptual estimates depending on movement amplitude observed in previous studies may also include the impact of planned endpoint locations.

To dissociate amplitudes and locations, we adopted an established procedure including variations of start locations (cf. e.g., Heuer and Klein 2006). The basic idea is illustrated in Fig. 1 (right part). If two movements of the same amplitude are planned from different start locations and an impact of this variation on perception is evident, then this effect can be attributed to planning of different endpoint locations.[1]

Experiment 1

We used a previously used "planning–perception–execution" paradigm (Kirsch et al. 2012; Kirsch and Kunde in press) and varied movement start locations and movement amplitude. Participants initially saw a movement cue indicating whether a given target should be overshot or undershot by 50 % of the target distance. Then, the target distance was presented and should be judged by adjusting two orthogonally presented dots. After this adjustment, the planned hand movement (50 % overshot or undershot) had to be performed according to the movement cue. Finally, participants moved to the start location for the next trial.

If variation in distance judgments is exclusively mediated by processes associated with the specification of amplitude during movement preparation, then the implemented change of start location should have no impact on perceptual estimates. That is, judgment behavior should only depend on planned movement amplitude, with larger amplitudes causing an increase in distance judgments. If, however, planning of endpoint location contributes to perception of a given target, then distance judgments should vary as a function of start location as well. A more distant start location and thus, a more distant endpoint location, should increase distance judgments as compared with a closer start location.

Methods

Participants

Twenty-two students of the University of Wuerzburg participated. They gave their written informed consent for the procedures and received course credit for their participation. One participant had a non-corrected visual impairment (myopia). His data were excluded from analyses. The final sample included 12 females and 9 males. The mean age was 21 years ranging from 18 to 25 years of age. Four of them reported to be left handers.

[1] Manipulating movement start position when movement amplitude is prescribed is essentially equivalent to manipulating the required end position. Yet, we prefer to describe this manipulation as one of start position, because this position is under full experimental control, whereas movement end positions depend on the way these movements are eventually carried out, and are thus less rigorously controlled.

Apparatus

The apparatus included a digitizing tablet (Wacom Intuos 2 A4), a digitizing stylus, a monitor, and a semi-silvered mirror (see Fig. 2). The tablet was positioned on a table. The monitor was placed approximately about 48 cm above the tablet. The mirror was built in between the tablet and the monitor. The mirror was approximately equidistant with respect to the tablet and the monitor. This construction allowed projections of virtual images in the plane of the tablet. The laboratory was dimmed during the experiment (only a remote table lamp was turn on to allow visibility of a keyboard). As a consequence, the mirror prevented the vision of the arm. The stimulus position indicating the position of the stylus on the tablet approximately corresponded to the real stylus position. One pixel of the monitor measured approximately .38 mm on the screen.

Procedure and design

The body midline of the participants was aligned to the middle of the monitor and of the tablet. The participants were asked to lean the forehead on an upper part of the apparatus in order to prevent head movements, to perform stylus movements with their right hand, and to make distance judgments with the left hand.

The main trial events are shown in Fig. 3. Each trial started with a movement of the stylus to the start position (gray point of ~2.5 mm in size). The reaching of the start position had to be approved by pressing a stylus button. In response to this key press, a symbolic cue was displayed that could be a gray circle (~55 mm) or a gray square (~55 × 55 mm). The cue was framed by a white rectangle (195 × 144 mm),

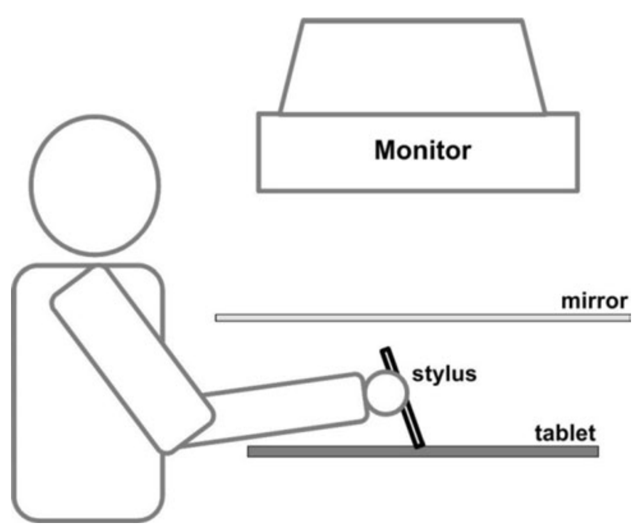


Fig. 2 Schematic illustration of the used apparatus

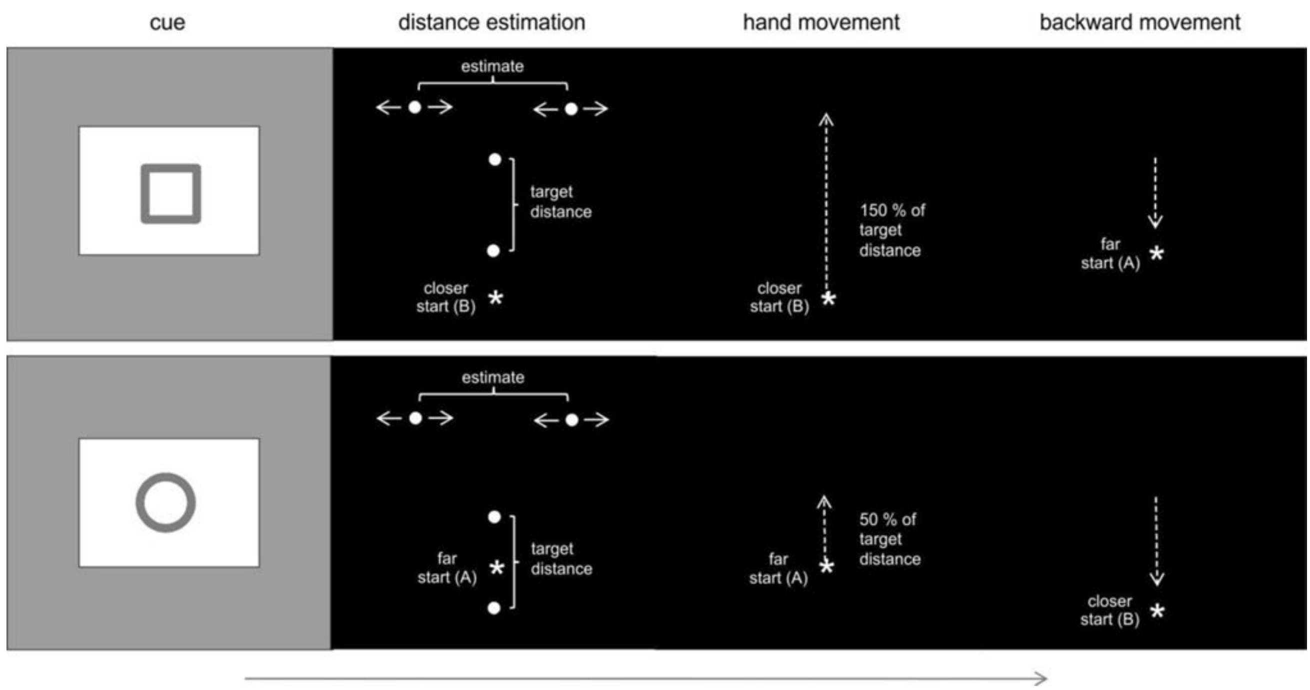


Fig. 3 Schematic illustration of two successive exemplar trials. During the hand movements, the virtual position of the stylus was presented in the form of a green circle. The movement cue requires participants to prepare a movement that is 50 % larger (*square* in this example) or shorter (*circle*) than a given target distance. Note, during the distance estimate, the start position was not visible (see text for other details)

whereas the residual display surface was gray. The cue informed about the movement that had to be executed after the following judgment of target distance. In particular, the participants were asked to reproduce either 50–150 % of the target distance by means of a hand movement. The assignment of the circles and squares to the movement instruction was counterbalanced across participants.

After the participant pressed the space bar, the cue disappeared and two gray points (~2.5 mm) appeared in the middle of the otherwise black screen. These two points served as targets the distance between which should be estimated. The distance judgment was done by pressing keys on the keyboard placed sidewise of the main apparatus. In response to a first key press, two additional points appeared at the top of the display to the left and right of the targets. These additional points were of the same color and size like the targets. Their initial distance randomly varied between approx. 50 and 150 % of the target distance.

The task was to adjust the horizontal distance (i.e., the distance between the left and right points) by pressing left and right arrow keys on the keyboard so that it was equal to the vertical distance (i.e., the distance between the targets). The pressing of one of the keys (discrete as well as continuous) led to an increase in the distance between the horizontal circles. The other key caused a decrease in the distance. During this adjustment procedure, the right and left points were equidistant with respect to the targets. The adjustment procedure was completed by pressing the enter key of the key board.

Following this key press, the horizontal points as well as targets disappeared and the current stylus position appeared as a green point (~2.5 mm). This served as a signal to initiate a stylus movement according to the movement cue. A stylus button had to be pressed after the movement was finished. In response to this button press, a gray circle (~2.5 mm) indicating the next start position was displayed. Additionally, a short text asked the participant to move the stylus to the start position. Thus, the manipulation of start position for a given trial was implemented during the backward movement of a previous trial and also before a movement instruction (i.e., cue) was displayed (cf. Fig. 3, right part).

There were three independent variables. The *movement instruction* could be to reproduce either 150 or 50 % of the target distance. The *target distance* was varied between 68 and 80 mm in steps of 4 mm (i.e., there were 4 target distances). Due to a restricted size of the digitizing tablet, we varied the absolute locations of these distances depending on the two start positions for movements. As a result, the manipulation of start position was confounded with the variation of some physical stimulus attributes, such as of egocentric stimulus positions (we examined this issue in Experiment 2). The *start position* was either 40 mm above the lower target (henceforth labeled as Start A, see also Fig. 3) or below the lower of two targets whose distance had to be judged (henceforth labeled as Start B). When the start position was below the lower target, the absolute coordinates of the targets on the display were shifted by 40 mm in depth as compared when the start position was above the lower target. For each start position, the position of the lower target was always constant and only the position of the upper target could change.

There were two blocks of trials with 32 trials each. In each block, each combination of target (4), movement instruction (2), and start position (2) conditions was presented twice in a randomized order. In order to reduce oversight mistakes, error feedback was given if (a) participants completed the judgment procedure without changing the position of the horizontal stimuli (b) performed a movement which was shorter as target distance when a large movement (150 %) was required and conversely, if they performed a movement the amplitude of which was larger than a given target distance when a small movement (50 %) was required (c) if movement amplitude was lesser than 7.6 mm (i.e., if no movement was performed). In these cases, the trial was repeated.

At the beginning of the experiment, participants performed eight practice trials, which did not enter the analyses.

Data analysis

In order to measure the accuracy of perceptual estimates, the difference between the horizontal and the vertical distances was computed (*constant perceptual error*). Positive perceptual error reflects overestimation of the target distance. Negative perceptual error indicates underestimation of the target distance. In order to measure the motor performance with respect to the movement instruction, we converted the recorded extent of the stylus movement (on the *Y-axis*) in % values with respect to each target distance (*relative movement amplitude*). Mean movement amplitude and mean perceptual errors were computed for each participant and each experimental condition.

Results and discussion

Motor performance

An analysis of variance (ANOVA) was performed including target distance (68, 72, 76, 80 mm), movement instruction (undershoot or overshoot), and start position (A top or B bottom) as within-subjects factors and relative movement amplitude as dependent variable. This analysis revealed significant main effects of movement instruction, $F(1, 20) = 264.0$, $p < .001$, of target distance, $F(3, 60) = 12.0$, $p < .001$, and of start position, $F(1, 20) = 49.7$, $p < .001$. Moreover, significant interactions were observed between movement instruction and target distance, $F(3, 60) = 9.1$, $p < .001$, start position and target distance $F(3, 60) = 6.8$, $p = .001$, and between start position and movement instruction, $F(1, 20) = 15.4$, $p = .001$. Figure 4 (left) illustrates mean values according to all experimental conditions. Participants performed on average movements of 64 and of 166 % amplitude with respect to the target distance under the movement instruction conditions of 50–150 % respectively. The manipulations of start position and of target distance, however, also affected movement extent. When the start position was below the lower target (Start B), the participants tended to make larger movements than when the start position was above the lower target (Start A). This difference was larger under movement instruction 150 % than under movement instruction 50 %. Also, when movement instruction was 150 %, participants tended to reduce the movement

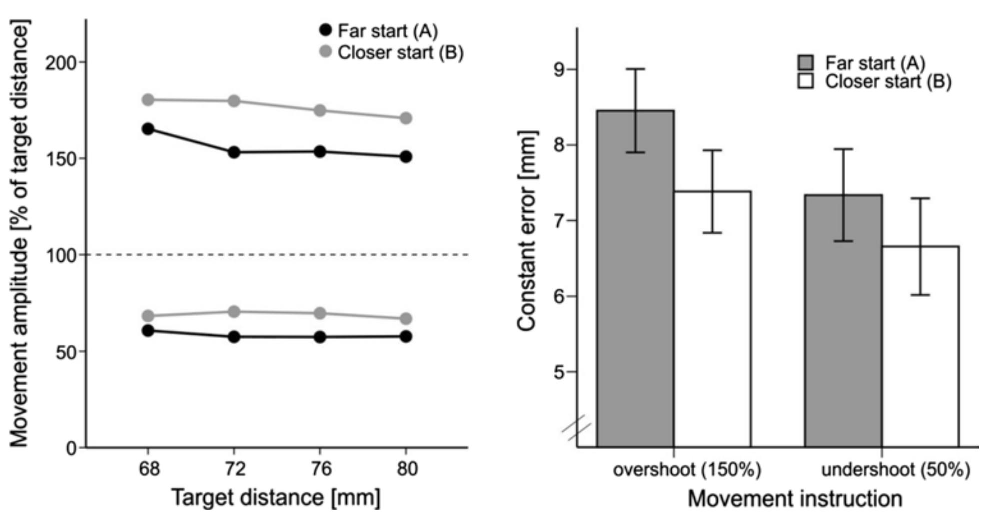


Fig. 4 Main results of Experiment 1. *Left* movement amplitude in % of target distance. *Right* mean constant error as a function of the movement conditions (i.e., of start position and movement instruction). *Error bars* are standard errors

amplitude for distant target locations. For the instruction 50 %, this trend was substantially smaller. Moreover, a similar pattern was true for the two start positions: the more distant start position (Start A) was associated with a larger decrease in amplitude with target distance than the start position B.

These results suggest that, by and large, participants followed the movement instruction. They appeared, however, to be somewhat worried that movements may extend the size of the digitizing tablet in conditions requiring relatively large movement amplitudes, that is, especially when a large movement (i.e., 150 %) has to be made from a distant start position to a distant target (although the physical size of the tablet was sufficient for the used target range: movements with an extent of up to 215 % of target distance were possible for the largest target distance and the distant start position).

These trends do not weaken the rationale of the present setup. The eventually most critical effect is the impact of changing starting position on the movement extent. The fact that participants made larger movement from a closer start position merely suggests that the originally desired magnitude of differences in end locations was not achieved. That is, if an impact of start manipulation, and thus, of variations in movement endpoint locations, on perceptual estimates of distances can be observed, then this result would suggest that a weaker manipulation than originally desired is sufficient to demonstrate this effect.

Constant perceptual error

We performed an analysis of variance (ANOVA) including target distance (68, 72, 76, 80 mm), movement instruction (undershoot or overshoot), and start position (A top or B bottom) as within-subjects factors. This analysis revealed significant main effects for movement instruction, $F(1, 20) = 7.60$, $p = .012$ and for start position, $F(1, 20) = 5.76$, $p = .026$ (all other $p > .504$[2]). As shown in Fig. 4 (right), participants generally overestimated the target distance (cf. also Kirsch et al. 2012; Kirsch and Kunde in press). More importantly, this bias was more pronounced in the 150 % movement instruction condition as compared with the 50 % condition. This result constitutes a conceptual replication of our previous results. Additionally, the overestimation bias was significantly stronger when the start position was above rather than below the first target. Thus, the results suggest that planning of movement endpoint location significantly contributes to perception of a visual target. In other words, with comparable movement amplitudes, visual distances were judged larger the further away the endpoint of a planned hand movement was.

There is one caveat, however. It might be that changes in the arrangement of the stimuli accompanying changes in start position affected distance judgments rather than changes in start position per se. To rule out this possibility, we performed a control experiment.

Experiment 2

The left part of Fig. 5 schematically illustrates the arrangement of all stimuli and of both starting positions used in Experiment 1. As shown, target stimuli were presented closer to the participant in case of the start position A as compared with the start position B. As a consequence of this confound of start position and the position of the stimuli, the effect of start position on the perceptual task observed in Experiment 1 may be, for example, due to a reduced magnitude of estimates for the distant target arrangement as compared with the closer presented targets (i.e., due to optical rather than to motor variables). We examined this issue in Experiment 2 by changing the assignment of start locations to (absolute) target coordinates (see Fig. 5, right part). That is, the start position A was now used for the distant target arrangement, whereas the start position B accompanied the closer target arrangement.

As in Experiment 1, participants were asked to perform movements of either 50–150 % of a given target distance. Also the start locations as well as target distances remained the same. Thus, if the effect observed in Experiment 1 is due to the changing start locations, then a similar pattern of results should also be observed in Experiment 2. If, however, differences in the physical arrangement of stimuli gave rise to the impact on distance estimates, then the effect of Experiment 2 should differ from Experiment 1.

Methods

Participants

Twenty-two participants were recruited. They gave their written informed consent for the procedures and received an honorarium for their participation. The data of two participants were excluded from analyses due to visual impairments (ametropia and strabismus). The final sample included 16 females and 4 males. Two of them reported to

[2] Note, the lack of a significant effect of factor distance does not indicate that participants could not discriminate between the given target distances because the reported analyses were based on deviations of estimated magnitude from the real distance. When the magnitude of distance estimates was considered a distance effect was evident, $F(3, 60) = 183$. In our previous study (Kirsch and Kunde in press) we observed distance effects also in perceptual errors indicating an increase of an optical illusion with an increase in distance. In the present study, this effect was not observed probably due to a much smaller target range (11 vs. 41 mm).

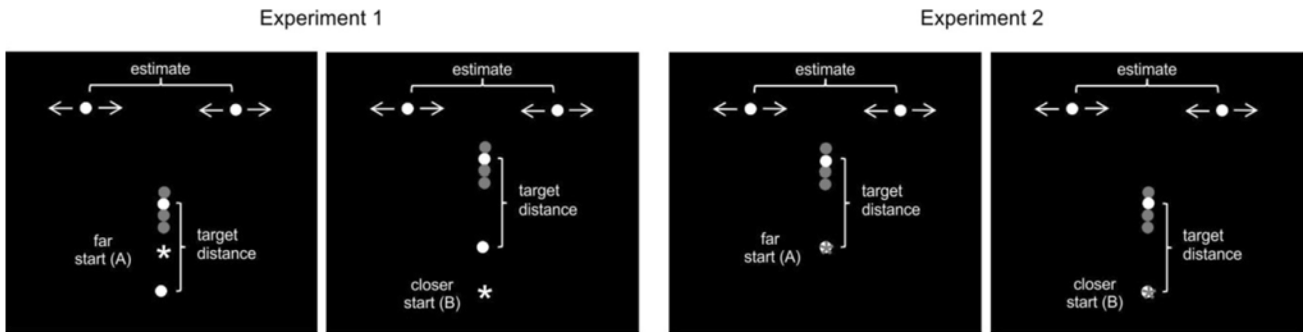


Fig. 5 The relation of the arrangement of stimuli to both start positions in Experiment 1 (*left*) and in Experiment 2 (*right*)

be left handed. The mean age was 24 years ranging from 16 to 30 years of age (SD = 4).

Procedure and design

Experiment 1 and Experiment 2 were identical apart from the location of target stimuli with respect to start position for movements. Keeping all coordinates of stimuli constant, we exchanged the start position A and B with one another (cf. Fig. 5).

All other details relating to the apparatus, procedure, and design as well as data analysis were the same as in Experiment 1.

Results and discussion

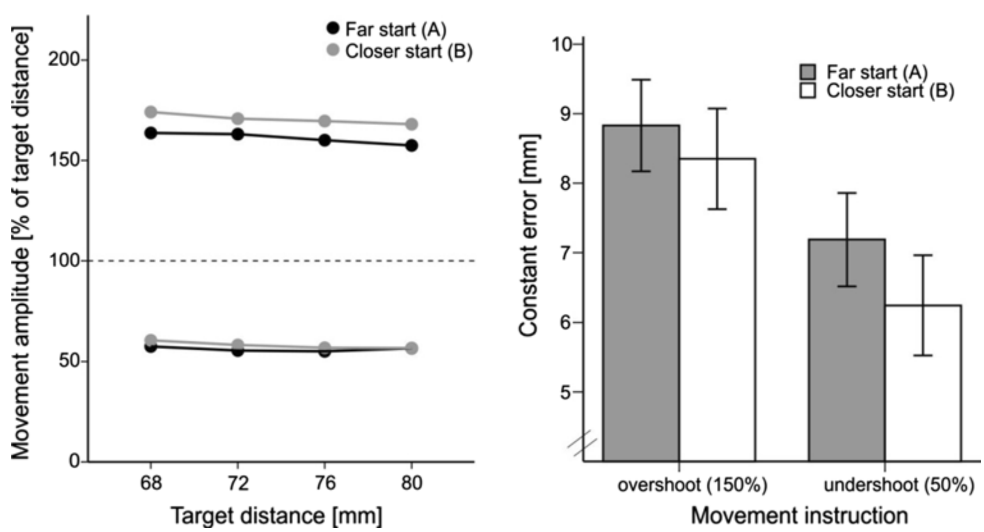
Motor performance

Figure 6 (left part) shows the means for the relative movement amplitude in all experimental conditions. An ANOVA including start position, movement instruction, and target distance as factors yielded significant main effects of all of these factors with $F(1, 19) = 24.9$, $p < .001$, $F(1, 19) = 406.5$, $p < .001$, and $F(3, 57) = 6.9$, $p < .001$, respectively. Also, a significant interaction was observed between movement instruction and start position, $F(1, 19) = 20.4$, $p < .001$. Participants consistently followed the movement instruction reaching 166 and 57 % of target amplitude on average in the movement instruction conditions 150 and 50, respectively. Moreover, analogously to the results of Experiments 1, there was a decrease in movement amplitude with an increase in target distance. Also, when the start position was at the bottom of the display (Start B), the participants made larger movements than when the start position was more distant (Start A). This effect was larger when movement instruction required 150 % than when movement instruction required 50 % of target amplitude. These results are similar to those of Experiment 1 and suggest that implemented manipulations of movement amplitude and of endpoint locations was successful.

Constant perceptual error

An ANOVA performed on the constant perceptual errors including target distance, movement instruction, and start position as factors yielded a significant main effect

Fig. 6 Main results of Experiment 2. *Left* movement amplitude in % of target distance. *Right* mean constant error as a function of the movement conditions. *Error bars* are standard errors



of movement instruction, $F(1, 19) = 18.4$, $p < .001$, and a marginally significant main effect of start position, $F(1, 19) = 3.6$, $p = .072$ (all other $p > .458$). Figure 6 (right part) shows the mean values according to the movement instruction and start position conditions. This pattern of results is rather similar to that of Experiment 1. Thus, differences in absolute positions of target stimuli do not appear to explain the results of both experiments. Rather, implemented changes in start position and thus, resulting changes in end locations of movements seem to contribute to the modulation of distance judgments. However, because manipulation of start position was still confounded with the absolute positions of target stimuli in Experiment 2, another analysis was needed to substantiate possible conclusions.

Joint analysis

To this end, we also performed an ANOVA on constant perceptual errors including experiment as between-subjects variable and target distance, movement instruction, and start position as within-subjects factors. This analysis revealed significant main effects for movement instruction, $F(1, 39) = 26.1$, $p < .001$, and start position, $F(1, 39) = 9.2$, $p = .004$. There was a tendency for an instruction × experiment interaction, $F(1, 39) = 3.0$, $p = .090$. This might indicate a tendency to a smaller movement instruction effect in Experiment 1 than in Experiment 2 and thus points to a slight impact of stimulus arrangement on judgment behavior. However, there was neither an interaction of start position and experiment nor an interaction of start position, movement amplitude, and experiment, which rules out that the impact of start position depended on differences of the stimulus arrangement between experiments (both $p > .315$).

These results, as a whole, strongly support the claim that in the present experimental setting, changes in start position for planned movements affected distance judgments additionally to the changes in instructed amplitude of movements.

General discussion

The main purpose of the present study was to examine whether planning of endpoint locations in hand movements affects the perception of visual stimuli in reachable space. To this end, we varied the amplitude and the start position of planned movements and examined the influences of these manipulations on judgments of distances. The results of two experiments indicated that both, the amplitude of forthcoming movements as well as the start position, affected perceptual judgments of target distance. According to the used rationale, changes in start position in the present setting are associated with changes in anticipated or planned endpoint locations of movements (cf. also e.g., Heuer and Klein 2006). Thus, the results suggest that changes in planning of movement endpoints may bias the perception of visual stimulus characteristics, such as of distances. This finding adds to an increasing number of reports indicating motor influences on perception (e.g., Bekkering and Neggers 2002; Gutteling et al. 2011; Linkenauger et al. 2009; Vishton et al. 2007; Witt et al. 2004) and supports the hypothesis that different features of planned movements can concurrently bias the visual perception in that situation (cf. Kirsch and Kunde in press).

It is widely accepted that several distinct variables are involved in control, planning, and memory of hand movements including, for example, amplitude, endpoint location, movement direction, and movement time (e.g., Gordon et al. 1994; Heuer and Klein 2006; Schmidt et al. 1988; Walsh et al. 1979). The relative involvement of these variables in a particular situation as well as the specific type of involved processes, such as of reference frames used during planning, appears to depend on task characteristics (e.g., Battaglia-Mayer et al. 2003; Heuer 2006; Heuer and Sangals 1998; Schmidt et al. 1988). Given this complexity of motor processes, several aspects of sensorimotor interactions in the present task remain elusive. For instance, which kind of motor information might have had an effect on perceptual estimates? In theory, position-based planning of movements may include some type of high-level variables such as a spatial endpoint position of intended movement as well as low-level information relating to final postures (e.g., Rosenbaum et al. 1999). Accordingly, at least two alternatives are possible. The present data does not allow established conclusions relating to this and similar questions but it indicates that a deeper understanding of perception–action interactions can be achieved by simultaneous focusing on discrete variables on the level of motor planning and of sensory processing.

Though it is important to dissect in a first step the movement features that affect visual perception, it is important in a second step to think of possible second-order movement variables on which these primary movement features map. One such variable might be movement effort (cf. e.g., Proffitt et al. 2003). It might be that we perceive distances as larger the more effort a concurrent body movement requires. The present result fit into this picture. Of two hand movements with the same amplitude, the one carried out further away from the body (with start position further away) requires larger effort. This is definitely so in terms of physical force due to larger leverages, but perhaps also in terms perceived effort. The observation that easy to grasp objects are judged nearer than hard to grasp objects fits into this picture (Linkenauger et al. 2009). The authors interpreted this result in terms of "perceived reachability" (see also "Introduction") suggesting that "how far people perceive the extent of their reach to be, provides a metric with which close distances can be scaled". However, grasping ease is closely related to movement costs and thus, to effort needed to grasp an object. Accordingly, in theory, the critical variable affecting perception may be related to energetic parameters of the forthcoming movement rather than be solely based on how far one can reach. In a similar vein, reaching for a target using a tool (e.g., Witt et al. 2005) may be less effortful than without a tool where locomotion is eventually needed. That is, an external stimulus may eventually appear closer to the observer not due to tool use or reaching ability per se, but due to smaller effort associated with planning a movement using a tool.

Alternatively, a critical variable mediating the effect on perception observed in the present study may also be more abstract and be, for example, spatial in nature. For instance, one may assume that a spatial representation of movement endpoint and a spatial representation of a stimulus interact at a certain processing stage. If so, then the impact of motor variables on perception will be mediated by the relationship between these two spatial landmarks. Perhaps some previously reported effects of tool use on perception are due to an interaction between spatial position of the movement goal (i.e., the end position of the tip of the tool) and the position of the target object to be judged (cf. e.g., Collins et al. 2008). For example, the effect of using a tool on perception reported by Witt et al. (2005) might reflect the smaller distance between the tip of the tool and the target than the distance between finger and target.

Both alternatives are not mutually exclusive. Identifying such underlying psychological movement variables that bias perception will certainly be an avenue worth to be taken for future research.

Proffitt and Linkenauger (2013) recently suggested that perception can be viewed as a phenotypic expression of organisms. In particular, people are assumed to scale spatial layout with those aspects of their morphological (e.g., arm length), physiological (e.g., energy expenditure), and behavioral (e.g., variability of errors) variables which are relevant for their intended action. Our present results are generally consistent with this approach: one can speculate, for example, that during movement preparation early sensory information related to the visual distance is enriched by the anticipated outcome of the action (i.e., intended endpoint of the movement) through a process of internal motor simulation (Witt and Proffitt 2008). However, the results also indicate that caution is needed in postulating of certain motor scales which may possibly be used as reference for perception. Given a nearly infinite number of possible motor variables which may be defined morphologically, physiologically as well as behaviorally, one promising approach could be to consider variables that are specified in planning motor acts in particular situations (cf. Kirsch and Kunde in press). This motor planning hypothesis allows testing of a priori predictions and may help to identify latent variables mediating action effects on perception within and across perceptual and motor contexts.

To conclude, the present results indicate that planning of movement endpoints may contribute to the perception of visual distances. An interesting question for future research is whether different kinds of movements (e.g., reaching, pointing and throwing) are differently susceptible to manipulations of endpoint location. Moreover, it would be worthwhile to examine whether reachability perception is affected by planning movements of varying extent. Also, using of motor versus spatial interference in a related task may allow isolating of the level of critical representations.

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