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Hitting ability and perception of object's size: evidence for a negative relation

Wladimir Kirsch · Elisabeth Königstein · Wilfried Kunde

Abstract We examined the relation between motor performance and perception of object's size in near space. The general task was to repeatedly hit a target by means of pointing movements and to estimate target's size. In contrast to the results of previous studies, Experiment 1 and Experiment 2 revealed a negative relation between action ability and perceived target size: Participants who hit the target relatively often and whose motor variability was relatively low judged targets to be smaller than did participants whose motor performance was relatively poor. In Experiment 3, the size judgments were made in the presence of the target before, as well as after, pointing movements. The target was judged as smaller when it was easy, rather than difficult, to hit before as well as after the movement. Altogether, these results indicate that under certain conditions, an increased action ability reduces the apparent size of the actions' target objects.

Keywords Embodied perception · Goal-directed movements · Perception and Action

Introduction

It has been reported several times that success or failure of an action correlates with size estimates of objects to which that action is related. For example, Witt and colleagues (Witt, Linkenauger, Bakdash, & Proffitt, 2008) observed that after a golf game, the golfers who played well estimated the hole size to be bigger than did golfers whose performance was worse on that day. Hitting performance in softball correlated with estimations of the ball's size (Witt & Proffitt, 2005). Again, players who hit well judged the ball to be bigger. The judgments of the size of goal posts in American football correlated with the kicking performance (Witt & Dorsch, 2009): More successful kickers judged the goal posts to be farther apart.

These and similar results were suggested to indicate action's effects on perception (e.g., Cañal-Bruland & van der Kamp, 2009; Wesp, Cichello, Gracia, & Davis, 2004; Witt, 2011). Specifically, people might see objects differently depending on their current action ability. The general idea behind this claim is that initial optical information is scaled by a kind of "perceptual ruler"—that is, by a motor variable that is relevant for an intended action (Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009; Proffitt & Linkenauger, 2013). One indication of action ability is the "variance of performance" (or the variance of probability distribution; Proffitt & Linkenauger, 2013). According to this approach, the perceived size of a target should increase with an increase in action ability (indicated by a decrease of action variability).

In spite of considerable evidence from other paradigms for this action-specific account of perception, the causal link between action ability and perception in studies on the relation between action success and the perception of object's size is not well supported. One possibly critical aspect of the previous results is that an effect of action on perception was typically observed in judgments measured when action outcome is known (but see Lee, Lee, Carello, & Turvey, 2012, for an exception). Accordingly, outcome evaluation processes might be related to the observed perceptual plasticity phenomena, rather than to the current action ability per se (cf. Cooper, Sterling, Bacon, & Bridgeman, 2012; Wesp et al., 2004).

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Moreover, assuming a close link between action ability and size perception, one might expect that the apparent size of an object varies with current ability already before action execution (cf., e.g., Kirsch & Kunde, 2013b; Witt & Proffitt, 2008). Two studies that looked at this issue, however, did not report systematic effects. Cooper and colleagues (2012) asked participants to throw a marble into a hole of varying size and measured verbal and haptic estimation of the hole size before and after movement. Participants judged the hole as larger after hits than after misses when the hole was occluded after throwing. Interestingly, a trend in the opposite direction (i.e., larger estimates on trials with misses; cf. Fig. 3) was observed in verbal estimation when judgments were made before and after movements while the target was visible.[1] Also, a trend toward a negative correlation across participants between hits and reported hole size was observed in the estimations made before movements. A similar pattern is reported by Witt and Dorsch (2009): Estimations of the size of an American football goal post made before kicking the football were negatively, although not in a significant manner, related to the number of successful kicks in the following game.

These observations suggest that high motor ability could go together with low size judgments at least before action execution. As was mentioned by Cooper et al. (2012), perceiving a target object as larger by a skilled actor could mean "that a successful hunter would perceive the prey as larger, and may therefore aim wide of the actual target and miss" (p. 236). Following this argument, an inverse relation between action ability and size perception could, under certain conditions, be even more advantageous from the evolutionally perspective that is often used to explain action's effects on perception (e.g., Witt, 2011).

Here, we present three experiments that, in fact, indicate that an increase in action ability can be associated with a decrease in apparent size of an action-relevant object. In Experiments 1 and 2, we aimed to replicate the previously reported "positive" relation between action ability and apparent target size when size judgments were measured after pointing movements. We failed to replicate that positive correlation. Instead, we consistently observed a negative correlation. Participants who hit the target relatively often and whose motor variability was low judged targets to be smaller than did participants whose motor performance was bad. On the basis of this result and similar observations in the literature (see above), we reasoned that an equivalent relation might be present already during movement preparation. Accordingly, in Experiment 3, we measured size judgments before pointing movements and observed results that confirmed the conjectured relation between action ability and perceived object's size.

Experiment 1

Participants were asked to hit visual targets by pointing movements under restricted feedback conditions. The visual feedback of the actual hand position was restricted to an initial portion of the movement. Target size and movement distance were varied. Following each movement, feedback was given about whether the target was hit or missed. Then participants were asked to judge the target size. This design allowed us to examine relations between motor performance and perceptual judgments on a trial-by-trial basis, as well as on the level of overall performance across participants. We expected to see a positive relation between action success and size estimations (i.e., more successful trials/participants should be associated with larger estimations than less successful trials/participants) and a negative relation between movement variability and judgments (i.e., more motor variability should be associated with smaller judgments).

Method

Participants

Twenty-two participants participated. They gave their informed consent for the procedures and received an honorarium or course credit for their participation. Size judgments of 1 participant deviated from the mean of the sample by more than 2 *SD*s, on average. His data were excluded from analyses. The final sample included 12 females and 9 males. The mean age was 28 years, ranging from 20 to 53 years of age (*SD* = 7). Two of them reported being left-handers. The sample size was chosen on the basis of our experience with similar setups and related research questions (cf., e.g., Kirsch & Kunde, 2013a, b). Sample sizes amounting to between 22 and 24 participants have proven appropriate in the past to demonstrate substantial systematics.

Apparatus

The used apparatus included a digitizing tablet, a digitizing stylus, a monitor, and a semi-silvered mirror (see Fig. 1). A monitor was fixated above a table. A digitizing tablet (Wacom Intuos 2 A4) was placed on the table. The distance between the monitor and the tablet was ~48 cm. A semi-silvered mirror was positioned in the middle between the monitor and the tablet. This apparatus allowed projections of virtual images in the plane of the tablet, whereas the mirror prevented the vision of the arm when the lab was dimmed. One pixel (px) of the monitor was approximately 0.38 mm in size on the screen.

Procedure and design

Participants sat so that the body middle corresponded with the middle of the monitor and of the tablet. They were also asked

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[1] The authors did, however, not report whether this difference was significantly different from zero.

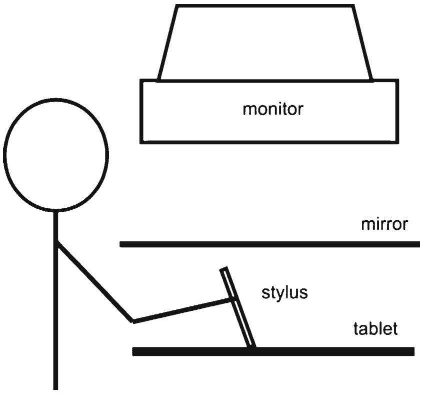

Fig. 1 Schematic illustration of the apparatus used

to lean their forehead on an upper part of the apparatus. Stylus movements were performed with the right hand, whereas size judgments were made with the left hand.

The main trial procedure is illustrated in Fig. 2. Before each trial, participants moved the stylus to the start position (blue dot of 4 px in size). The position of the stylus was indicated by a gray dot (4 px) that approximately corresponded to the real position of the stylus. After reaching the start position, a target (a gray filled circle) was displayed additionally to a short text asking to initiate the next movement. The task was to hit the target with the stylus. After a half of the distance (related to *y*-coordinates) was covered, the visual feedback of the stylus position disappeared. Participants had to press the stylus button after finishing the intended movement. In response to this keypress, the target changed its color for 500 ms from gray to green when it was a hit and from gray to red when it was a miss. During this initial phase, the current number of hits achieved in a given block of trials (see below) was continuously presented above the target (cf. Fig. 2).

After a delay of 2 s, during which the display was black, participants were required to reproduce the size of the target. For this purpose, a gray circle was displayed at the position of the target, additionally to a short text asking to start the judgment. The initial radius of this circle corresponded either to a half of the target radius or to one and a half of the target radius. The task here was to adjust the size of the circle to the size of the previously seen target by pressing left and right arrow keys on the keyboard. The pressing of the right key (discrete as well as continuous) led to an increase of the size. The left key caused a decrease of the size. The estimation was completed by pressing the Enter key of the key board. If the Enter key was pressed without changing the initial circle size, an error feedback was presented after which the judgment procedure was repeated.

Following this judgment procedure, a blue dot indicating the next start position and a short text asking the participant to move the stylus to the start position appeared. Also, after a half of the previous target distance was passed, the gray dot indicating the actual stylus position was shown.

The target always appeared at a viewing distance (i.e., the distance between the eye and the projection of the target on the level of the tablet) of about 54 cm (i.e., its position was constant). The movement distance was varied along the depth dimension by displacing the start position between 110 and 440 px in steps of 110 px with respect to the center of the target (i.e., there were four movement distances, amounting to about 3.8, 8.0, 12.5, and 17.3° of visual angle). The target radius could be 15, 20, 25, or 30 px (i.e., the visible target size corresponded to approximately 1.2°, 1.6°, 2.0°, or 2.4° of visual angle). There were three blocks of trials with 32 trials each. In each block, each combination (of target size and movement distance) was presented twice in a randomized order. Between the blocks, the achieved number of hits was reset, and the participants were asked to try to improve their motor performance and the quality of judgments in the next block. At the beginning of the experiment, participants performed 8 practice trials, which did not enter the analyses.

Data preprocessing

Trials on which movement time was longer than 10 and in which measured movement amplitude was less than 50 px were excluded. Subsequently, trials on which estimated radii, movement times, and movement amplitudes were below or above 2.5 *SD*s of the mean as computed for each participant, each target, and each target distance were also excluded. Overall, 98.6% of trials entered the analyses.

Results and discussion

The hit rates increased with an increase in target size and decreased with an increase in movement distance, as would be expected according to Fitts's law (Fitts & Peterson, 1964; see Table 1 for means). We converted the observed hit rates to arcsine values and then statistically analyzed these arcsine values (e.g., Sokal & Rohlf, 1981). An analysis of variance (ANOVA) including target size and target distance as within-subjects factors revealed significant main effects for both factors, with $F(3, 60) = 50.1$, $p < .001$, $\eta_p^2 = .715$, and $F(3, 60) = 90.2$, $p < .001$, $\eta_p^2 = .818$, respectively.

To examine the dependency of size judgments and motor performance across participants, we computed spatial deviations of movement end points from the center of the targets for each trial according to $D = \mathrm{SQRT}((X_m - X_t)^2 + (Y_m - Y_t)^2)$, where X and Y are screen coordinates of the given target (X_t, Y_t) and of the end point of the movement (X_m, Y_m). Then, standard deviations (*SD*s) of D were calculated for each target size and each participant. Finally, these variability scores were averaged across the four targets for each participant, providing an index of motor variability (IMV). Accordingly, this measure can be considered as an indicator of how consistent participants' aiming movements were.

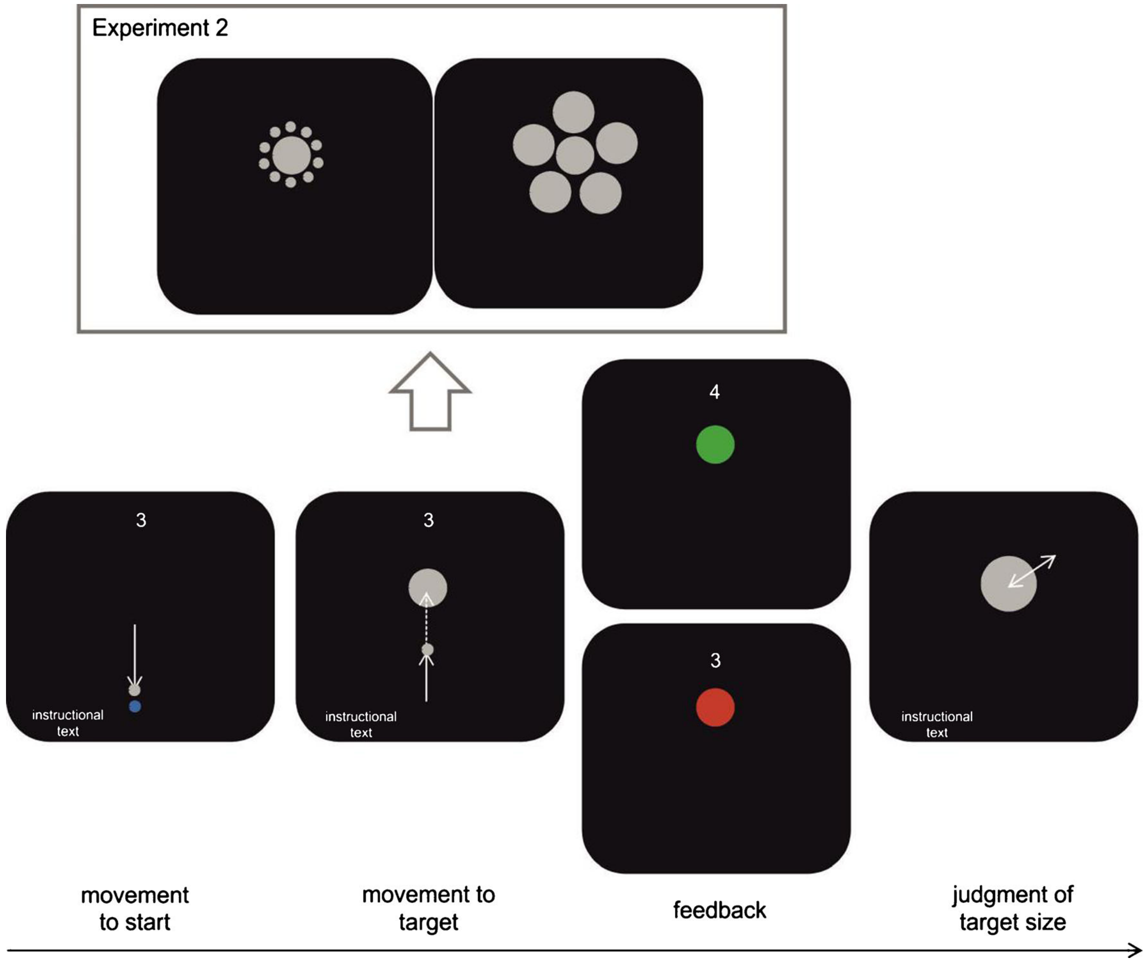

Fig. 2 Schematic illustration of the main trial events in Experiment 1 and in Experiment 2. Note, a delay of 500 ms between the feedback and the judgment (in which the display was black) was omitted. The location of the start position (blue dot) and the size of the target varied. Arrows indicate the direction of stylus movements (left part) and of possible size changes of the comparison stimulus during size judgments (right part). A small gray dot shown at the ends of the arrows indicates the actual position of the stylus. It was visible only when the distance between the actual stylus position and the start position did not exceed a half of the distance between the start position and the target (denoted by a dashed line)

Figure 3 (left part) illustrates the relation of the IMV and the perceptual judgments of target size (computed analogously to the IMV). As is shown, participants with high motor variability tended to judge targets as bigger than did participants with low motor variability, $r = .448$, $p = .042$. We also correlated mean hit rates (computed analogously to the IMV) with size judgments (see Fig. 3, right part). This analysis revealed a marginally significant correlation in the same direction; hence, the higher the error rate was, the smaller targets were judged, $r = -.375$, $p = .094$.

One possible caveat of this result is that participants who performed well saw the target more often getting green and less often getting red before judgment (i.e., during the feedback phase). Accordingly, it might be, for example, that the

Table 1 Fitts's index of movement difficulty (ID in bits, bold) and mean hit rates (in percentages) in each experimental condition of Experiment 1 (with standard deviations in parentheses)

Target Radius (px)		**15**	**20**	**25**	**30**
Movement Distance (px)	**110**	**2.9** / 67.0 (31.4)	**2.5** / 81.7 (27.3)	**2.1** / 88.1 (23.7)	**1.9** / 94.4 (15.2)
	220	**3.9** / 39.0 (25.1)	**3.5** / 60.3 (27.1)	**3.1** / 59.0 (27.5)	**2.9** / 81.0 (24.3)
	330	**4.5** / 25.1 (21.0)	**4.0** / 48.4 (31.1)	**3.7** / 48.6 (28.2)	**3.5** / 62.7 (32.0)
	440	**4.9** / 20.7 (21.4)	**4.5** / 30.3 (27.1)	**4.1** / 32.5 (26.1)	**3.9** / 47.1 (33.9)

Note. ID = $\log_2$ (2 * movement distance / target diameter).

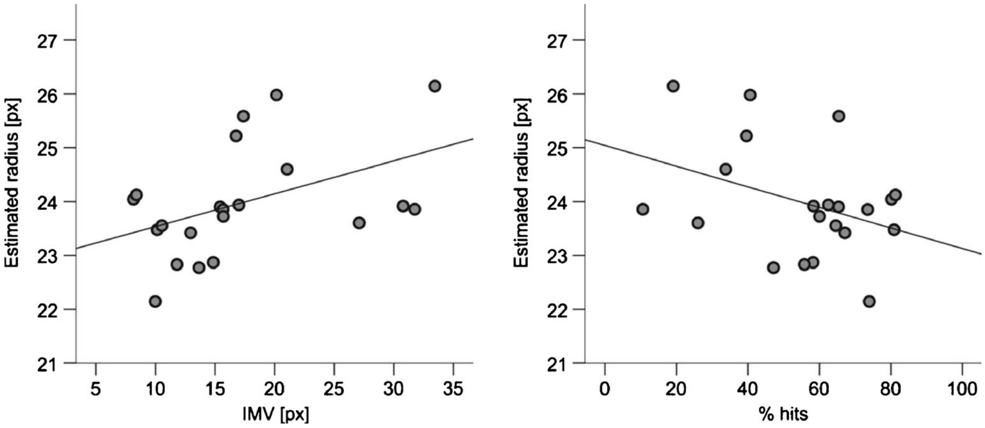

Fig. 3 Mean judgments of target radius as a function of motor variability scores (IMV, left) and of mean hit rates in Experiment 1. Each circle represents 1 participant's data (means were computed for all distances and each target initially and then averaged across all targets)

color green may make a target appear bigger, rather than processes associated with good performance. For control for this confound, we correlated the IMV with the perceptual judgments including only misses. That is, only trials on which feedback color was constant (but motor performance varied) were analyzed. The corresponding correlation coefficient was positive, $r = .385$, and marginally significant, $p = .085$, indicating that motor performance, rather than feedback color, modulated perceptual estimates (cf. also Experiment 2).

We then analyzed the data depending on whether the aiming movement was successful or not (cf. Cooper et al., 2012). Initially, mean estimates of target size were computed for each participant, each target, and each category of action success (hits, misses). Two participants did not reveal any misses for the biggest target, and were, thus, not included in the following ANOVA. The mean values of the remaining participants were subjected to an ANOVA using target size and action success as within-subjects factors. This ANOVA revealed significant main effects for both factors, with $F(3, 54) = 615.2$, $p < .001$, $\eta_p^2 = .972$, and $F(1, 18) = 5.5$, $p = .030$, $\eta_p^2 = .236$.[2] Mean values of this analysis are shown in Table 2. The estimates of target size increased with target size. More important, hits were associated with smaller estimates (23.8 px), as compared with misses (24.3 px). This result, however, should be considered with some caution, since the magnitude of the observed effect was very small (0.5 px) and it was below the resolution of the monitor (1 px).

To summarize, the main finding of Experiment 1 was that participants who showed a relatively high degree of variability in motor behavior and who missed the target relatively often tended to judge target size as larger than did participants who were more consistent during aiming movements and who missed the targets less often. An analysis of trial-by-trial variations of motor behavior pointed to the same direction: Judgments after hits were associated with smaller size estimates than were judgments made after misses. Although we expected to find a systematic relation between motor performance and perceptual estimates on the basis of previous research, the direction of the observed effect was the opposite of the predicted direction.

Experiment 2

With Experiment 2, we aimed to replicate the pattern of results observed in Experiment 1. Thus, the main task and the procedure were taken from Experiment 1. Additionally, we were interested in whether visual illusions induce changes in motor behavior, as reported by Witt, Linkenauger, and Proffitt (2012). This study reported increased sport performance in a putting task when smaller context stimuli surrounded a hole, as compared with larger context stimuli. Accordingly, we also implemented a version of the Ebbinghaus illusion, in which the central target is surrounded by small versus large context stimuli. Here, an increase in hit rates was expected with small, as compared with large, context stimuli. Finding such an effect would moderately strengthen the ecological validity and the generalization of the results observed in Experiment 1.

Moreover, the setup of Experiment 2 allowed us to test whether the used method of adjustment is sensitive to changes in apparent target size. Demonstrating an increase in size estimates with small, as compared with large, context stimuli (i.e., the Ebbinghaus illusion) would indicate that changes in judgment behavior following stylus movements are due to subjective changes in perceived target size, rather than to other task-specific factors (relating, e.g., to the used judgment procedure or stimuli).

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[2] When the missing values were replaced by the mean of the sample, the results did not change substantially.

Table 2 Mean estimates of target radius across the target and action success conditions of Experiment 1. Standard deviations are shown in parentheses

Target Radius (px)		**15**	**20**	**25**	**30**
Action Success	**hits**	16.5 (1.3)	20.9 (1.5)	26.5 (1.4)	31.3 (2.0)
	misses	16.6 (0.9)	21.6 (1.2)	26.6 (1.6)	32.2 (2.8)

Method

Participants

Twenty-four participants were recruited.[3] They gave their informed consent for the procedures and received an honorarium or course credit for their participation. One participant had a visual impairment (dyschromatopsia). His data were excluded from analyses. The final sample included 15 females and 8 males. The mean age was 22 years, ranging from 18 to 28 years of age (*SD* = 3). One of them reported being a left-hander.

Procedure and design

Experiment 1 and Experiment 2 were very similar, with few exceptions. Instead of four targets, we used only two with radii of 20 px (1.6°) and 25 px (2.0°) in Experiment 2. Additionally, we varied the context of the targets by including additional gray circles surrounding the target. In one condition, 10 context circles were small (5 px) and were either 30 px (smaller target) or 35 px (larger target) away from the target (center to center). In another condition, 5 context circles were relatively big (35 px) and were either 60 or 65 px away from the target.

Data preprocessing

Data preprocessing was performed in an analogous way as in Experiment 1. Initially, trials with movement times longer than 10 s and with movement amplitudes less than 50 px were excluded. Then trials on which estimated radii, movement times, and movement amplitudes were below or above 2.5 *SD*s of the mean (computed for each participant, each target, each target context, and each target distance) were also excluded. Overall, 97.2% of trials entered the analyses.

Results and discussion

As in Experiment 1, (to arcsine values converted) hit rates increased with target size and decreased with movement distance, $F(1, 22) = 39.1$, $p < .001$, $\eta_p^2 = .640$, and $F(3, 66) = 64.3$, $p < .001$, $\eta_p^2 = .745$ (see Table 3 for means of untransformed hit rates). Moreover, the interaction between movement distance and target context was marginally significant, $F(3, 66) = 2.5$, $p = .068$, $\eta_p^2 = .102$. For three of four distance conditions, the smaller context stimuli were associated with larger hit rates, as predicted. Thus, the results of Witt et al. (2012) could partially be replicated. This indicates that the inter- and the intraindividual variations of size estimates with action characteristics observed in Experiment 1 (and in Experiment 2; see below) generalize to another experimental setting.

To examine the relation between motor behavior and judgments, we again correlated perceptual estimates of target size with motor variability scores (IMV), as well as with hit rates across participants. Figure 4 shows the corresponding scatterplots. In both analyses, the corresponding correlation was significant, $r = 593$, $p = .003$, and $r = -.728$, $p < .001$. The analysis of the relation between IMV and judgments including only trials on which the target was missed (cf. Experiment 1) revealed an *r*-value of .498, $p = .016$, indicating that feedback color cannot account for the observed differences in perceptual estimates.

Analogous to Experiment 1, perceptual estimates were split and averaged according to action success (see Table 4 for mean values). One participant had to be excluded from the analyses of mean values because of one missing value[4] (larger target, small context, misses). An analysis of size judgments using an ANOVA with target size, target context, and action success as factors revealed significant main effects for target size and context, $F(1, 21) = 569.3$, $p < .001$, $\eta_p^2 = .964$, and $F(1, 21) = 44.5$, $p < .001$, $\eta_p^2 = .679$, and a significant interaction between action success and context, $F(1, 21) = 7.0$, $p = .015$, $\eta_p^2 = .249$. Besides the trivial effect of target size, this result indicated the expected impact of visual illusion on perceptual estimates: With small context stimuli, the target was judged to be bigger ($M = 26.1$ px) than with large context stimuli ($M = 24.1$ px). Moreover, the observed action success × context interaction suggested that when the context stimuli were small, there was a decrease in judgments for hits (25.8 px), as compared with misses (26.3 px), $F(1, 21) = 7.9$, $p = .011$, $\eta_p^2 = .273$. For the larger context stimuli, in contrast, there was no significant differences between both action success conditions, $F(1, 21) = 0.4$, $p = .555$, $\eta_p^2 = .017$. Thus, similar to Experiment 1, when targets were surrounded by small context stimuli, there was a tendency to judge the target as smaller after a hit than after a miss.

To sum up, participants who were less consistent in aiming movements and who made more errors judged the target as bigger than did participants who showed a relatively small

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[3] We planned to have in Experiment 2 and 3 approximately as many participants as in Experiment 1. In the end, there we 24 participants available at the point in time the data collection took place. We preferred to retain the additional power.

[4] Replacing this value by the mean of the sample in the corresponding condition did not substantially change the results.

Table 3 Fitts's index of movement difficulty (ID in bits, bold) and mean hit rates (in percentages) in each experimental condition of Experiment 2 (with standard deviations in parentheses)

Target Radius (px)		**20**		**25**	
Context Stimuli		**Small**	**Large**	**Small**	**Large**
Movement Distance (px)	**110**	**2.5** / 76.5 (27.1)	**2.5** / 67.7 (30.9)	**2.1** / 86.7 (21.0)	**2.1** / 83.8 (21.9)
	220	**3.5** / 52.5 (23.2)	**3.5** / 49.9 (31.1)	**3.1** / 63.0 (32.6)	**3.1** / 56.7 (31.5)
	330	**4.0** / 40.9 (28.5)	**4.0** / 42.7 (32.6)	**3.7** / 41.4 (33.2)	**3.7** / 50.6 (27.6)
	440	**4.5** / 28.1 (24.0)	**4.5** / 25.4 (25.1)	**4.1** / 44.3 (29.2)	**4.1** / 34.6 (29.6)

degree of variability in motor behavior and who missed the target rarely. An analogous relation between motor performance and size estimates was also seen in the analysis of individual estimates split according to hits and misses: Estimates made after hits were associated with smaller size judgments than were estimates made after misses. This, however, was only true in the presence of small context stimuli. Thus, by and large, the main finding of Experiment 1 could be replicated. Moreover, the applied method of adjustment appears suitable to measure changes in apparent target size, because the typically observed Ebbinghaus illusion was found here as well. This suggests that changes in judgment behavior following stylus movements were due to subjective changes in perceived target size, rather than to other task-specific factors.

Experiment 3

The goal of Experiment 3 was threefold. First, the method of adjustment used in the previous experiments appeared to be insufficiently sensitive to detect variations in estimations of target size depending on action success within participants (even though some small effects were observed). Thus, the main conclusions drawn from the data were mainly based on correlative analyses that preclude inferences about a causal impact of motor performance on perception, due to a lack of the criterion of experimental manipulation. Accordingly, we sought for a more sensitive judgment method. Second, because the target was not visible in the previous experiments, the results might reflect some memory-related, rather than perceptual, distortions (cf. Cooper et al., 2012). We thus aimed to change the procedure so that a possible impact of memory-related processes would be unlikely. Third, given evidence from other paradigms that motor variables can affect perceptual processing before an action is executed (e.g., Kirsch & Kunde, 2013a; Witt & Proffitt, 2008) and given some indices from other hitting tasks pointing to a negative relation between action ability and perceived target size (see the Introduction), we aimed to measure target's perception not only after, but also before movement execution.

We tried to realize these aims using a task in which participants judged the size of a target circle by choosing one of two comparison circles that were of very similar (although never of the same) size as the target object (cf. Fig. 5). In the critical condition, the radius of one comparison stimulus was 1 px smaller, whereas the radius of the other comparison stimulus was 1 px larger than the radius of the target. The judgments were made before and after each pointing movement aimed at the target.

The critical experimental variation was again related to movement distance, which was expected to impact action success. Two main predictions were tested. First, if the results

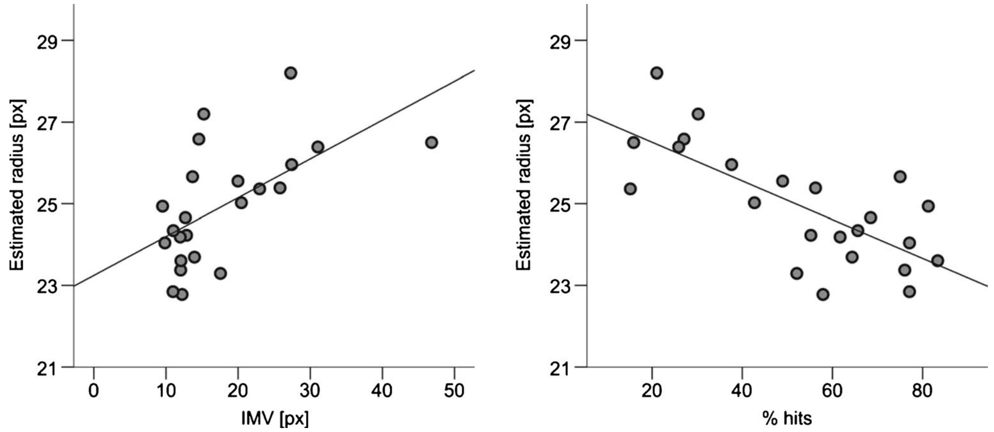

Fig. 4 Mean judgments of target radius as a function of motor variability scores (IMV, left) and of mean hit rates in Experiment 2. Each circle represents 1 participant's data

Table 4 Mean estimates of target radius across the target, context, and action success conditions of Experiment 2 (with standard deviations in parentheses)

Target Radius [px]		**20**		**25**	
Context Stimuli		**Small**	**Large**	**Small**	**Large**
Action Success	**hits**	23.4 (1.7)	22.0 (2.4)	28.2 (2.0)	26.3 (1.7)
	misses	23.8 (1.3)	21.7 (1.9)	28.9 (1.6)	26.3 (1.7)

observed in the two previous experiments were, in fact, due to perceptual distortions, an increase in movement distance (and a corresponding increase in error rates predicted by Fitts's law) should prompt a preference for the larger over the smaller comparison circle after pointing (corresponding to an increase in apparent target size; cf. also Experiments 2 and 3 in Witt et al., 2008, for a related rationale). A lack of such an outcome would indicate that the previously observed changes in size judgments are due to an impact of processes related to the memory of the target, rather than to its perception. Second, if the perception of target size is already affected by action preparation (see above and the Introduction), larger comparison stimuli should be preferred with larger movement distances (higher error rates) already during movement preparation. Finding that this was not so would suggest a significant role of action execution (and/or of the evaluation of action outcome) in the occurrence of movement-related changes in size estimates.

Method

Participants

Twenty-four participants participated. They gave their informed consent for the procedures and received an honorarium or course credit for their participation. The data of 1 participant were not complete, due to technical reasons (program crash). Her data were excluded from analyses. The mean age of the remaining participants (2 males) was 21 years, ranging from 18 to 26 years of age (*SD* = 2). One of them reported being a left-hander.

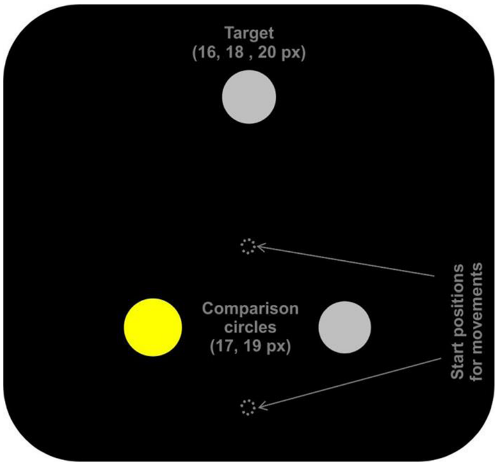

Fig. 5 Configuration of the stimuli during the judgment procedures in Experiment 3. Note that neither the current stylus position nor the current start position was visible during the judgment

Apparatus

The apparatus used was the same as in the previous experiments, except for the digitizing tablet, which was replaced by a larger one (Intuos 4 XL, Wacom). The distances between the new tablet, the mirror, and the monitor were slightly readjusted to maintain optical conditions.

Procedure and design

As in the previous experiment, participants moved the stylus to the start position before each trial. After the stylus reached the start position, a gray target circle and two gray comparison circles were displayed in additional to a short text asking the participant to judge the given target size by choosing one of the comparison circles (cf. Fig. 5). This was done by pressing the left or the right arrow keys on the keyboard. The pressing of the left key caused the left comparison circle to change its color from gray to yellow. The right key led to the color switch of the right comparison circle. The judgment could be corrected and was completed by pressing the Enter key of the keyboard. If the Enter key was pressed without changing the color of one of the comparison circles or when the cursor left the start position, an error feedback was presented, after which the judgment procedure was repeated.

Following this initial judgment, the comparison circles disappeared, and a stylus movement was performed in the same way as in the previous experiments (i.e., under restricted feedback conditions). After the movement was completed, the target changed its color for 500 ms, indicating whether it was hit (green) or missed (red). Additionally, during this feedback phase, the endpoint of the movement was also displayed as a gray dot. Then the initial judgment was repeated. When movement distance (related to y-coordinates) amounted to less than 50 % of the current target distance or the judgment was confirmed without changing the color of the comparison circles, an error feedback was presented, and the trial was immediately repeated.

The position of the target was always constant (viewing distance was approximately 54 cm), whereas the position of the start was varied between 245 and 490 px with respect to the center of the target (i.e., movement distance amounted about 9° and 19° of visual angle). The target radius could be 16, 18, or 20 px (1.29°, 1.46°, or 1.62°). The comparison circles were always 19 px (1.76°) and 17 px (1.57°) in size, 200 px (9.3°) apart from each other (from center to center), symmetrical with respect to the start and target positions (i.e., with respect to the *y*-axis of the start and the target), and approximately in between the two start positions (i.e., the *y*-coordinate of the comparison circles was in the middle between the *y*-coordinates of the start positions). The middle-sized target (18 px) was the critical target condition, whereas the smaller and the larger targets, which constituted a rather easy task given the size of the comparison circles, primarily served for checking purposes.

There were three blocks of trials with 60 trials each. In each block, each combination (of target size and movement distance) was presented 10 times in a randomized order. Importantly, the spatial positions of the comparison circles varied randomly from trial to trial for the first and second judgments separately (i.e., the lager/smaller circle could unpredictably appear at the same or at a different position for both judgments).

At the beginning of the experiment, participants performed 12 practice trials, which did not enter the analyses. We also encouraged the participants to make an effort to repeatedly hit the target by offering additional payment or credit points for achievement of more than 100 hits (the total number of hits was not reset between the blocks, as in the previous experiments).

Data preprocessing

Due to the implemented improvement of the procedure, especially regarding the control of the movement, the data appeared to have no substantial outliers. We thus included all data in the analyses.[5]

Results and discussion

The hit rates increased with an increase in target size and with a decrease in movement distance (see Table 5). An ANOVA including target size and movement distance as factors and arcsine transformed hit rates as a dependent measure revealed significant main effects for both factors, with $F(2, 44) = 23.4$, $p < .001$, $\eta_p^2 = .515$, and $F(1, 22) = 131.3$, $p < .001$, $\eta_p^2 = .856$, respectively.

Figure 6 illustrates the results of the judgment behavior measured before and after the stylus movement. Shown are the percentage choices of the larger comparison circle (19 px). In the smaller (16 px) and larger (20 px) target conditions, participants decided for the smaller (17 px) and larger (19 px) comparison circles, respectively, on the majority of trials. In these rather easy task conditions, there were no differences between the two distance conditions (*t*-tests with arcsine transformed percentage values, $p > .4$). For the critical middle target, in contrast, participants chose the larger comparison circle significantly more often when the movement distance was large, as compared with the smaller distance. This was true for the judgments made before the movement, $t(22) = 4.2$, $p < .001$, as well as for the judgments made after the movement, $t(22) = 2.6$, $p = .017$.

We also analyzed the judgment data of the middle target condition depending on whether the target was hit or not (see Fig. 7). An ANOVA with movement distance and action success (hit, miss) as factors and with the arcsine transformed percentage values as a dependent variable revealed a significant main effect of movement distance for the judgment made before the movement, $F(1, 22) = 15.7$, $p = .001$, $\eta_p^2 = .417$ (other *ps* > .5). An analogous analysis performed on the postmovement judgments, in contrast, revealed a significant main effect of action success, $F(1,22) = 4.9$, $p = .037$, $\eta_p^2 = .182$ (other *ps* > .1).

Thus, the results of Experiment 3 conceptually replicated the results of Experiment 1 and of Experiment 2 in that the target was judged to be larger after a miss than after a hit. Additionally, difficult to hit targets were judged larger than easy to hit targets already during movement preparation. This observation might indicate that the critical level of interaction between the motor and the visual systems is related to the estimation of target distance, rather than to the target size. It is well known that the perceived size of an object depends on perceived distance of that object (Holway & Boring, 1941). If the size of the retinal image remains constant, an increase in perceived distance results in an increase of perceived size as predicted by Emmert's law (cf., e.g., Gregory, 2008). Accordingly, the observed increase of apparent target size with an increase in movement amplitude before movement execution may indicate an increase in the perceived distance to the (actually constant) position of the target. In other words, a target may appear larger because it is perceived as farther away. This would imply that motor signals relating to the intended movement were used as depth clues for the calibration of the perceived size of the target.

On the basis of this argument, one can also assume that the difference between hits and misses observed after movement execution is due to differences in perceived distance between these conditions. To test for this possibility, we analyzed constant motor errors (i.e., deviation of movement end position from the target position along the *y*-axis) in the critical target condition, using an ANOVA with movement distance and action success (hit, miss) as factors. Trials on which the target was missed were, in fact, associated with a stronger underestimation ($M = -3.6$ and $M = -4.5$ px for the smaller and larger distances, respectively), as compared with trials on which the target was hit ($M = -1.1$ and $M = -0.8$ px). However, the main effect of action success did not reach

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[5] We also ran the analyses including similar outlier criteria as in Experiments 1 and Exp. 2 (trials with movement times above 10 s, as well as trials with movement times below or above 2.5 *SD*s of the mean, were excluded). These analyses revealed essentially the same results as those presented below.

Table 5 Fitts's index of movement difficulty (ID in bits, bold) and mean hit rates (in percentages) in each experimental condition of Experiment 2 (with standard deviations in parentheses)

Target radius (px)		**16**	**18**	**20**
Movement distance (px)	**245**	**3.9** / 69.6 (14.3)	**3.8** / 75.7 (10.8)	**3.6** / 81.7 (11.4)
	490	**4.9** / 39.9 (17.7)	**4.8** / 48.0 (20.6)	**4.6** / 57.1 (21.0)

significance, $F(1, 22) = 2.5$, $p = .127$, $\eta_p^2 = 103$ (other ps > .7). Thus, the data leave it open how far possible changes in distance perception may account for the observed changes in target size.[6]

It is also notable that individual percentage of choices of the larger comparison circle in the middle target condition tended to be negatively related to the hit rates achieved by the participants: Participants who hit the target relatively seldom tended to choose the larger comparison circle more often than did participants who hit the target relatively often. The correlation coefficients for the pre- and postmovement judgments ($r = -.330$ and $r = -.321$) did, however, not reach the significance threshold ($p = .124$, $p = .135$). One obvious reason for these, as compared with the previous two experiments, rather weak relations is that there was less interindividual variability in hit rates across participants in the critical condition of Experiment 3: All mean values were between 33% and 85 %. This was certainly the result of the feedback of the end position of the movement, according to which participants could better learn to adjust their motor behavior after misses.

To sum up, the hypotheses that were derived on the basis of the data of Experiments 1 and 2, as well as on some indices from the literature, appear to be well supported by the results of Experiment 3. Thus, conclusions mainly drawn from correlative data were substantiated by experimental evidence and suggest that an increase in action ability may, in fact, lead to a decrease in perceived size of an object to which action is related.

General discussion

The main purpose of the present experiments was to examine the relation between action ability and the perceived size of action targets. Participants repeatedly judged the size of circular target objects after (Experiments 1 and 2) and before (Experiment 3) they tried to hit them from different start locations. On the basis of the results of previous studies, we hypothesized that an increase in motor performance will be associated with an increase in perceived target size. In the present three experiments, however, we observed results that point to an opposite pattern: Good performance was related to a decrease in perceived target size. That is, participants whose motor performance was relatively good tended to judge targets as smaller than did participants whose motor performance was relatively bad. Additionally, for judgments made after the movement, trials with successful movements were associated with smaller estimates than were trials on which targets were missed (but see the large context condition in Experiment 2 for one exception). For judgments made before the movement, a similar pattern was observed: When the target was easy to hit, it was judged to be smaller than when it was more difficult to hit.

Despite the unexpected direction of the observed effects, the results are nevertheless in line with the general idea of action-oriented accounts of perception, due to an obvious relation between action ability and perceptual estimates (e.g., Witt, 2011). Moreover, a possible role of motor variability as a critical variable mediating an impact on perception in goal-directed actions seems also to be supported by the present results (e.g., Proffitt & Linkenauger, 2013). However, these ideas appear insufficient, at least at present, to explain why an increase in action ability may increase, as well as decrease, the size of an action-relevant object.

We can, of course, only speculate about the exact origin of the observed findings, which we have to take serious given the robustness of the observations. One possible explanation could be that the varying motor difficulty was accompanied by a variation of perceived target distance (see also Experiment 3). When the task appeared rather easy (e.g., when the movement distance was small), the given target position could be perceived as closer than when the task appeared more difficult. As a result, the same proximal stimulus (i.e., the retinal image of the target) was perceived as smaller according to the perceptual dependence of size and distance (e.g., Holway & Boring, 1941). If so, then some motor signals associated with planned or executed actions can be assumed to affect perceived visual distance in the present setup (i.e., to act as depth clues; cf. also, e.g., Kirsch & Kunde, 2013a). In other words, the observed decrease in target size with an increase in action success (and with a decrease in movement distance) could be due to a decrease in perceived distance to the target.

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[6] It should be noted that a motor bias could be affected by some biomechanical factors and/or some processes relating to sensorimotor transformations. Thus, using this measure as an indicator of distance perception might not be straightforward. Accordingly, the observed lack of a significant difference between hits and misses does not rule out a possible difference in distance perception between these conditions.

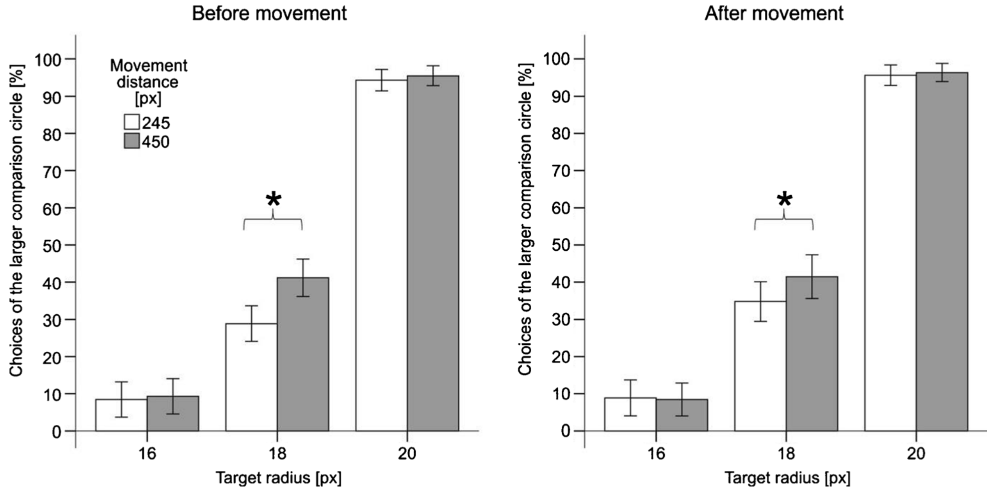

Fig. 6 Percentages of choices of the larger comparison circle (19 px) in each target and movement distance condition. Asterisks denote significance ($p < .05$), as indicated by *t*-tests including arcsine transformed choices. Error bars reflect between-subjects standard errors

Another possibility is that under the present conditions, the varying task difficulty is associated with changes in allocation of attentional resources. If the pointing task appears rather difficult to a participant (in general or on a particular trial), he or she will probably make more effort to hit the target than when the task appears rather easy (even though he or she generally will have less success if the task is difficult). One way to do so is to focus more attention at the center of the target (which can be assumed to increase the spatial resolution of the central target area). Such a strategy can, in fact, modulate the perceived size of an object in the observed direction (see Anton-Erxleben & Carrasco, 2013, for a review) and can possibly enhance chances for a hit in the present task. Anton-Erxleben, Heinrich, and Treue (2007), for example, demonstrated that drawing spatial attention to the center of a visual stimulus increases its perceived size (see also Fortenbaugh, Prinzmetal, & Robertson, 2011, for similar results).

This assumption, however, does not appear to hold for other related results indicating a positive relation between motor ability and perception of stimulus attributes (Cañal-Bruland & van der Kamp, 2009; Wesp et al., 2004; Witt & Dorsch, 2009; Witt & Proffitt, 2005; Witt et al., 2008; see also the Introduction). Reasons for the discrepancy between these studies and the present experiments may be manifold. One possible critical difference is that perceptual estimations were often made after a series of motor responses in previous experiments and after each motor response in the present experiments. Accordingly, the previous findings might reflect a more general impact of overall performance on perception, whereas the present results may be assumed to capture ability–perception interactions more precisely. In particular, when the outcome of a series of actions is known, evaluation and memory processes conceivably modulate the judgment of a given target. For instance, a good performer may think, after a

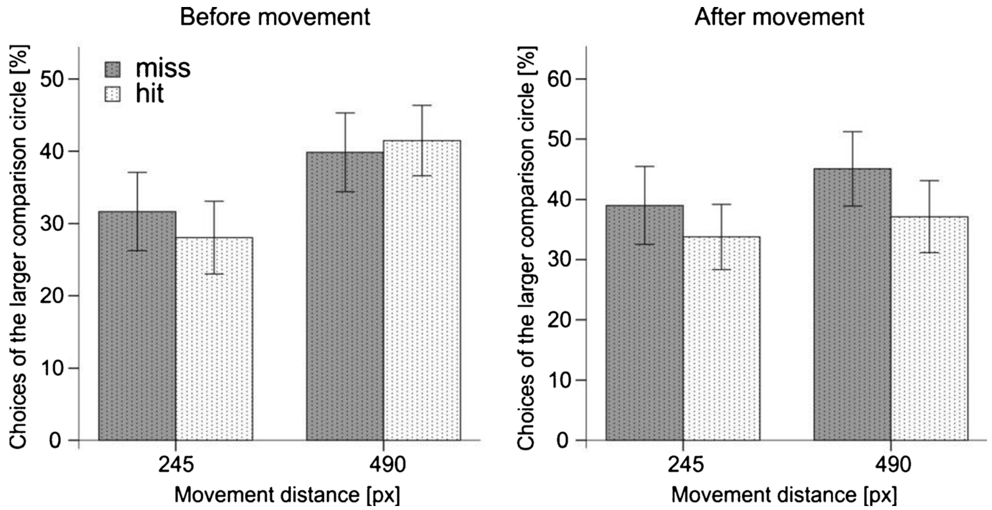

Fig. 7 Percentages of choices of the larger comparison circle (19 px) in the middle target condition (18 px) for movement distance and action success (hit, miss) separately. Error bars are standard errors

successful performance, that a target was/is rather big just because the performance was successful, whereas a poor performer may conclude that the target was/is small just because it was rather difficult to hit (cf. also Cooper et al., 2012, p. 236; Wesp et al., 2004, p.1265).

If so, then a critical difference between previous studies and the present experiments relates to differences in the involvement of such evaluation processes in memory. A relatively high temporal proximity of motor and perceptual events, as well as a relatively large number of estimations implemented in the present experiments, might have prevented extensive evaluation of each action outcome. Accordingly, attributional heuristics mentioned above were hard to apply. Using only a few estimations after a series of actions, in contrast, may facilitate stimulus evaluation based on known action consequences and, thus, may lead to a positive relation between action ability and apparent object's size.

It is also conceivable that the critical mechanism underlying positive, as well as negative, relationships between ability-related and perceptual measures is the same irrespective of the observed effect direction that is the result of given task conditions. In previous studies, for example, the (objective) difficulty of the motor task was typically constant for all participants (but see Experiments 2 and 3 in Witt et al., 2008). Accordingly, larger estimates given by more successful actors could reflect the fact that they exerted more resources to hit the target (e.g., by focusing more attention at the center of the target, as mentioned above) and, hence, were more successful. In the present experiments, however, the task difficulty considerably varied as a result of the implemented changes in target size and in movement distance. Under these conditions, a rather difficult task (e.g., a small movement distance and high proportion of misses) certainly requires more cognitive resources than a rather easy task (e.g., a short movement distance and high proportion of hits). Since the motor performance is still worse in the difficult condition, a negative relation between action success and size estimates can emerge (see also above). In a similar vein, participants with low hit rates could be those who made more effort to hit the target under present conditions, having, however, limited success as compared with more skillful participants.

So far, we have argued for an impact of action on the *perception* of target size. Given that the results of Experiment 1 and of Experiment 2 (in which target size had to be remembered) were conceptually replicated in Experiment 3 (in which judgments were made in the presence of the target), memory processes do not appear to substantially modulate the observed relationship. As was mentioned by a reviewer, however, this reasoning might not be without a gap: Since the comparison and target circle could not be precisely viewed at the same time in Experiment 3, memory processes might still be taking place during the size comparison. If so, then the observed relationship could be related to other process besides direct perception (Cooper et al., 2012).

To conclude, the present experiments indicate that an increase in action ability may be associated with a decrease in the apparent size of an object to which action is related. This outcome suggests that the previously reported evidence for a positive relationship between action success and perceived target size is not generally valid and is the result of certain task variables. Identifying conditions under which motor ability affects perception in a certain direction might be an interesting question for future research.

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