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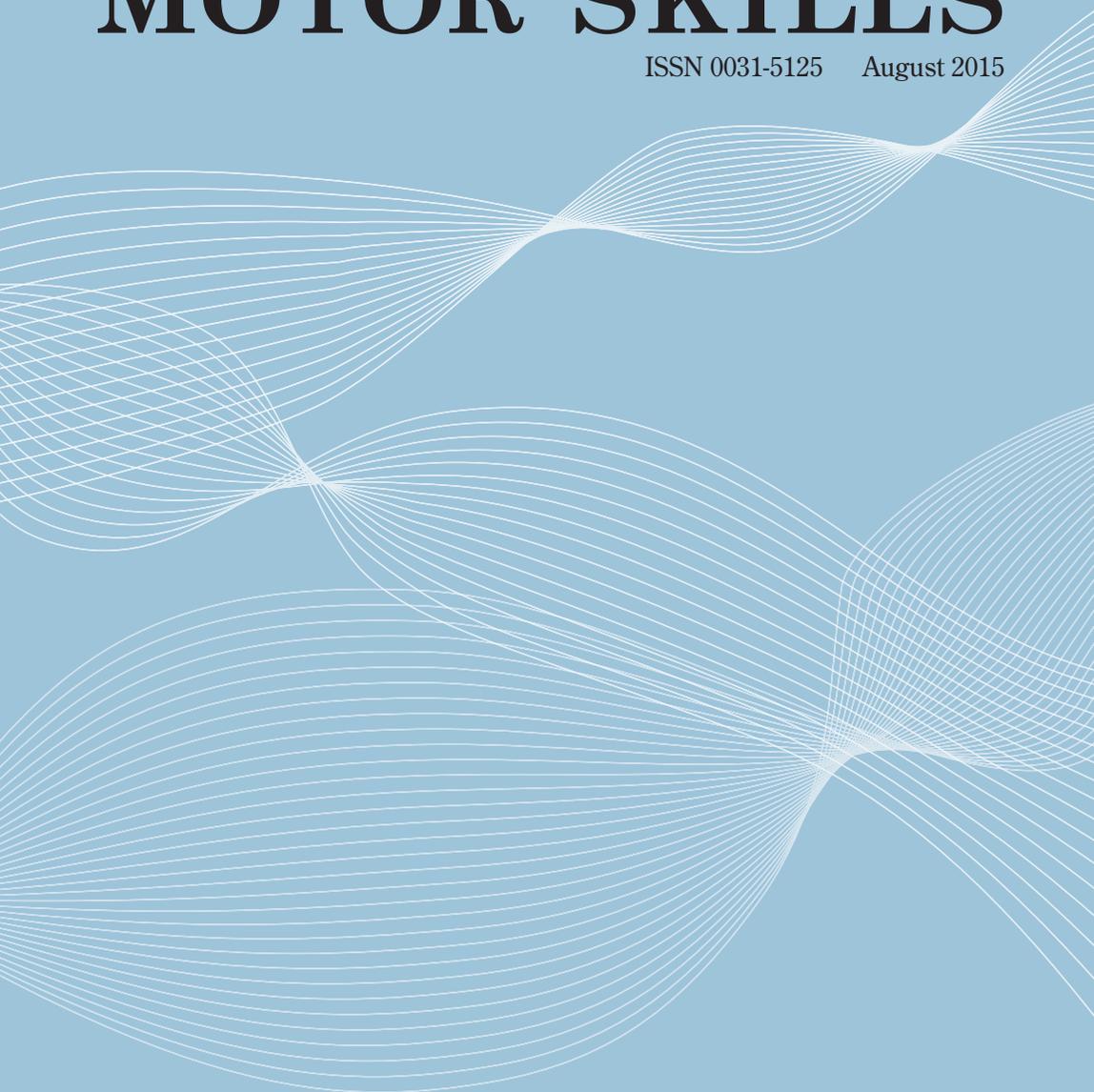
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PERCEPTUAL & MOTOR SKILLS

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SECTION 1: EXERCISE & SPORT

Warm-up Protocols for High School Students: DIMITRIS ELEYTHERIOS CHATZOPOULOS, ATHANASIOS YIANNAKOS, MARIANA KOTZAMANIDOU, AND ELENI BASSA 1

Self-efficacy, Emotional States, and Performance in Carom Billiards: DONATELLA DI CORRADO, FRANCESCA VITALI, CLAUDIO ROBAZZA, AND LAURA BORTOLI 14

Methodological Considerations to Analyze the Relation of Physical Activity with Leptin Levels in Children: Comment on Cicchella, et al. (2013): DAVID JIMÉNEZ-PAVÓN 26

Use of Trans-Contextual Model-based Physical Activity Course in Developing Leisure-time Physical Activity Behavior of University Students: MİNE MÜFTÜLER AND MUSTAFA LEVENT İNCE 31

SECTION 2: LEARNING & MEMORY

Effects of Stroboscopic Visual Training on Visual Attention, Motion Perception, and Catching Performance: LUKE WILKINS AND ROB GRAY 57

A Pilot Study on the Encoding of a Perceptual Learning Task Following Sleep Deprivation: KELLY K. MCWHIRTER, ANNE S. MORROW, BETH A. LEE, SHRINIVAS BISHU, ALAN J. ZAMETKIN, THOMAS J. BALKIN, CAROLYN B. SMITH, AND DANTE PICCHIONI 80

Effective Indices for Monitoring Mental Workload While Performing Multiple Tasks: BIN-WEI HSU, MAO-JIUN J. WANG, CHI-YUAN CHEN, AND FANG CHEN 94

SECTION 3: MOTOR SKILLS & ERGONOMICS

Postural Control Mechanisms in Healthy Adults in Sitting and Standing Positions: PILAR SERRA-ANÓ, LAURA LÓPEZ-BUENO, XAVIER GARCÍA-MASSÓ, MARÍA TERESA PELLICER-CHENOLL, AND LUIS-MILLÁN GONZÁLEZ 119

The Launch Window Hypothesis and the Speed-accuracy Trade-off in Baseball Throwing: JONATHAN FREESTON, RENE E. D. FERDINANDS, AND KIERON ROONEY 135

Arm Movement as a Cue for the Estimation of Visual Location: WLADIMIR KIRSCH AND WILFRIED KUNDE 149

The Importance of Negative Acceleration of the Load in Free-style Lifting: JORDAN TRAFIMOW, JOSEPH XAYGNARAJ, DAVID TRAFIMOW, AND ALEXANDER S. ARUIN 163

Effect of Energy Drinks on Selected Fine Motor Tasks: B. H. JACOBSON, P. P. HUGHES, E. C. CONCHOLA, G. M. HESTER, AND C. L. WOOLSEY 170

SECTION 4: PERCEPTION

Children's and Adults' Judgments of Facial Trustworthiness: The Relationship to Facial Attractiveness: FENGLING MA, FEN XU, AND XIANMING LUO 179

Attributes of Aesthetic Quality Used by Textile Conservators in Evaluating Conservation Interventions on Museum Costumes: JOHANNA NILSSON AND ÖSTEN AXELSSON 199

Effects of Colors on the Feeling of Being Dazzled Evoked by Stimuli with Luminance Gradients: MITSUHIKO HANADA 219

Developing Numerical Ability in Children with Mathematical Difficulties Using Origami: ÁGOTA KRISZTIÁN, LÁSZLÓ BERNÁTH, HAJNALKA GOMBOS, AND LAJOS VERECZKEI 233

SECTION 5: PHYSICAL DEVELOPMENT & MEASUREMENT

Association of Subjective Ratings to Objectively Assessed Physical Activity in Pubertal Boys with Differing BMI: TRIIN RÄÄSK, EVELIN LÄTT, TOIVO JÜRIMÄE, JAREK MÄESTU, JAAK JÜRIMÄE, AND KENN KONSTABEL 245

Fundamental Movement Skills of Preschool Children in Northwest England: J. D. FOULKES, Z. KNOWLES, S. J. FAIRCLOUGH, G. STRATTON, M. O'DWYER, N. D. RIDGERS, AND L. FOWEATHER 260

Predictors and Trends of Gross Motor Skill Performance in At-risk Elementary School-aged Children: RYAN D. BURNS, TIMOTHY A. BRUSSEAU, YOU FU, AND JAMES C. HANNON 284

The Relative Age Effect in Combat Sports: An Analysis of Olympic Judo Athletes, 1964–2012: MAICON R. ALBUQUERQUE, EMERSON FRANCHINI, GUILHERME M. LAGE, VARLEY TEOLDO DA COSTA, ISRAEL T. COSTA, AND LEANDRO F. MALLOY-DINIZ 300

Proficiency at Object Control Skills by Nine- to Ten-year-old Children in South Africa: The NW-CHILD Study: A. E. PIENAAR, M. VISAGIE, AND A. LEONARD 309

ARM MOVEMENT AS A CUE FOR THE ESTIMATION OF VISUAL LOCATION^{1,2}

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Summary.—Two experiments including 24 (*M* age=29 yr., *SD*=9; 6 men) and 25 participants (*M* age=27 yr., *SD*=9; 8 men), respectively, examined how arm movement extent affects the perception of visual locations. Linear arm movements were performed on a horizontal plane from a start position until an auditory signal occurred. Subsequently, the position of a visual target located along the movement path was judged. The target was judged as further away with an increase in movement extent. The results indicated that motor-related signals are taken into account in visual perception of locations. There were no indications, though, that changes of location perception prompted subsequent changes of action planning, which demonstrates the short-term nature of action-induced plasticity of space perception under the present conditions.

It is widely accepted that the visual system integrates several types of information about an object's distance, such as occlusion, relative size, convergence, and accommodation (see Cutting & Vishton, 1995, for a review). A recent line of research demonstrates, however, that changes in visual perception not only result from changes in optical and oculomotor cues but also from variations of certain variables related to the body and its movements (see Proffitt, 2008; Witt, 2011; Proffitt & Linkenauger, 2013, for reviews and, e.g., Firestone, 2013, for criticism).

For example, when hand movements with large (as compared with small) amplitude are planned, distances in grasping space are judged as larger (e.g., Kirsch, Herbort, Butz, & Kunde, 2012; Kirsch & Kunde, 2013a, 2013b). This effect was measured by means of a matching procedure depicted in Fig. 1. Participants were asked to judge spatial intervals in depth (sagittal plane) by adjusting spatial intervals in a frontoparallel plane (perpendicular to the line of sight). An increase in the amplitude of hand movements planned along the sagittal plane was associated with an increase in distance estimates. This result indicated that some variables relating to the planning of movement extent affect the perception of space. However, it is not clear at present which specific spatial features are affected by the variation of movement amplitude. Motor variables could alter

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either the perceived distance between two objects or the perceived locations of those objects (or both) under the mentioned conditions.

The main purpose of the present study was to scrutinize influences of movement amplitude on perceived object location. If distances and locations are considered in Euclidian coordinate systems, then asking observers about the locations of two objects is equivalent to asking them about the distance between those objects. However, psychologically, distances and locations are actually not interchangeable (e.g., Loomis, Da Silva, Philbeck, & Fukusima, 1996). For example, a relative distance between two objects can be derived without egocentric localization of those objects (Gogel, 1963). Also, distance and location information are differently susceptible to visual illusions (Abrams & Landgraf, 1990). This indicates that a motor variable can have differential effects on distance and location perception. Consider, for example, an observer who moves a cup of coffee from Location A to Location B (e.g., from the bottom to the top location in Fig. 1). He could possibly indicate that the apparent distance between these locations increases as the weight of the cup increases (cf. Kirsch & Kunde, 2013b). However, this possible change in the perception of relative (i.e., "exocentric") distance would not necessarily imply changes in the perception of each location (i.e., of egocentric distances to Locations A and B). Hence, asking observers about objects' distances and objects' loca-

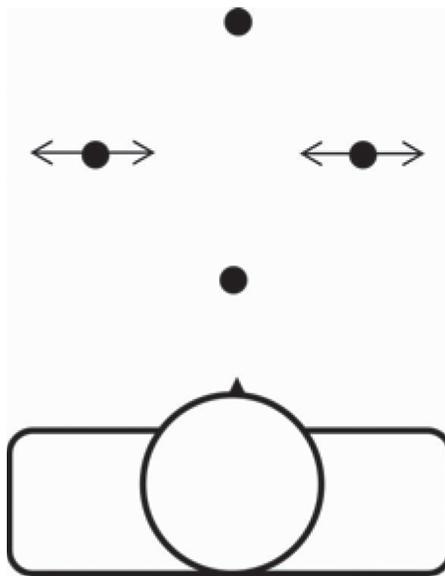


FIG. 1. Measuring distance perception by a method of adjustment (see main text for further details).

tions reflects two dissociable aspects of space perception. At present, it is unknown if both these aspects of space are affected by changes in the amplitude of hand movements.

It is well known that the perception of an object's location is subject to diverse distortions. For example, when asked to indicate the final location of a moving stimulus, participants' judgments often shift in the direction of motion (Freyd & Finke, 1984). Also, static stimuli presented in the retinal periphery are perceived as more foveal than they actually are (e.g., van der Heijden, van der Geest, de Leeuw, Krikke, & Müsseler, 1999). Beyond stimulus properties, both phenomena depend on cognitive factors including observer's expectancies, intentions, and attentional focus (e.g., Hubbard, 1995; Jordan, Stork, Knuf, Kerzel, & Müsseler, 2002; Bocianski, Müsseler, & Erlhagen, 2010). Moreover, there is evidence that indicates a close link between these phenomena and the control of eye movements and thus suggests that motor processes affect the perception of an object's location (Müsseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999; Kerzel, 2000; Kerzel, Jordan, & Müsseler, 2001; Stork, Müsseler, & van der Heijden, 2010). Against this background it seems conceivable that the perception of an object's location can vary as a function of the amplitude of concurrently performed hand movements.

In the present study, the participants were asked to move a stylus along a linear trajectory toward a visual target on a digital pad and to stop moving the stylus after they heard a tone. Then, the current target location was judged. The tone occurred so that the stylus movement could be stopped substantially before the target, near the target, or substantially behind the target.

Hypothesis 1. If movement information is indeed included in the estimation of target location, the target should be judged as being located further away with an increase in movement extent.

In Experiment A, visual feedback of the current stylus position was continuously presented during the movements (but not during the judgment). Therefore, visual consequences of the movement may be responsible for possible effects on judgment behavior, rather than movement extent *per se*. In particular, the visual feedback of the current stylus position can serve as an anchor during the estimation of target location and can affect the judgment irrespective of the real stylus position (or real movement extent). In this case, a potential effect would be visual in nature and would not be directly related to the actual movement. To assess the potential contribution of such movement consequences, a second experiment (B) was conducted in which the visual feedback of the stylus position was omitted. Finding an increase in the location estimates with an increase

in movement extent in Experiment A but not in Experiment B will raise doubts whether this effect is directly related to motor variables. Otherwise (i.e., if the effect of interest is present in both experiments), an effect of motor variables on location perception will be supported.

Beyond this primary issue, the present design allowed exploration of whether motor-related changes of perceived object location would prompt subsequent changes of action execution. Such changes of behavior are assumed in action-specific approaches to perception (Proffitt, 2006; Witt, 2011). Altered perception is considered to induce adaptive behavior, such that, for example, a hunter who sees a prey as small because of low current aiming capabilities moves closer toward the prey to increase hunting success. Here this issue was addressed by trial-to-trial correlational analyses. The study analyzed whether the variation in movement amplitude among subsequent trials is partly or even fully mediated by changes of perceived object location. In essence, movement amplitude in a given trial (n) was correlated with the movement amplitude in a preceding trial ($n-1$). This was made to access possible adjustments of the current movement that are due to the movement of the previous trial. Then the same analysis was performed using location judgments in Trial $n-1$ as a control variable. Thus, it has been examined whether current movement adjustments can be explained by the preceding judgment behavior.

Hypothesis 2. If perceptual changes indeed affect subsequent behavior as suggested (see above), then holding the location judgments constant should decrease the inter-movement correlation.

METHOD

Participants

Twenty-four right-handed participants participated in Experiment A (M age = 29 yr., SD = 9; 8 men) and 25 right-handed participants participated in Experiment B (M age = 27 yr., SD = 9; 8 men). They were recruited by means of advertisements distributed through a local e-mail distribution list (including potential participants), a social network, or a local online-newspaper. Five participants of Experiment B also participated in Experiment A. They gave their informed consent for the procedures and received an honorarium or course credit for their participation.

Apparatus

The main apparatus consisted of a graphics tablet (Intuos 4 XL, Wacom), a digitizing stylus, a monitor, and a semi-silvered mirror. A monitor was mounted above a table on which the tablet was placed. The monitor-tablet distance was about 47 cm. The mirror prevented vision of the hand in the dimly lit laboratory and allowed projections of virtual images in the

plane of the tablet. It was mounted centrally between the monitor and the tablet. One pixel (px) of the monitor measured approximately 0.38 mm. Headphones were used for the presentation of acoustic signals.

Procedure and Design

The participants sat in front of the apparatus so that their body midline was approximately in the middle of the monitor and of the tablet. They were asked to lean their forehead on an upper part of the apparatus during the experiment in order to reduce head movements. Stylus movements were performed with the right hand. Perceptual estimations were made with the left hand using a conventional keyboard placed to the left of the apparatus.

Figure 2 outlines the basic trial procedure and the arrangement of stimuli. At the beginning of each trial the participants were asked to move a stylus on the graphics tablet along a linear trajectory toward a visual target (gray dot, ~2 mm in size) that remained visible throughout the trial until the judgment was finished (see below). After a certain distance was covered an acoustic signal was presented (a sequence of short beep tones, 2,000 Hz). The participant's task was to stop the movement in response to this signal, to press a stylus key located at the bottom part of the stylus (near the tip),³ and to keep the stylus in the stopped position. The key press turned the sound off. Subsequently, the position of the (still visible) target was judged by means of two comparison stimuli (gray lines, 5.7 mm in length) presented 70.3 mm to the left of the target. The lines were 0.38 mm thick and 1.52 mm apart. The participant was asked to press a button on the keyboard to indicate which of the two lines was closer to the position of the target. Pressing the upper/lower arrow key changed the color of the further/closer line from gray to yellow. The position estimate was confirmed by the enter key. In response to this key press, the target and the comparison lines disappeared and the start position appeared. This was a signal to move the stylus back to the start position that was constant through the experiments.

The participants were encouraged to perform rather slow movements and to stop the movement immediately after the stop signal. An error feedback was presented and the current trial was repeated when the stylus key was pressed before the stop position was reached or when the distance between the end position of the stylus and the position at which the stop signal was presented exceeded 38 mm.⁴ In those cases, the following text appeared at the screen for 1,000 msec. (in German): "Error! You made a wrong movement. The trial will be repeated."

³The participants usually pressed it using the index finger.

⁴This value took into account a delay between the stop signal and the end point of the movement as well as the expected variability in movement velocity across the participants.

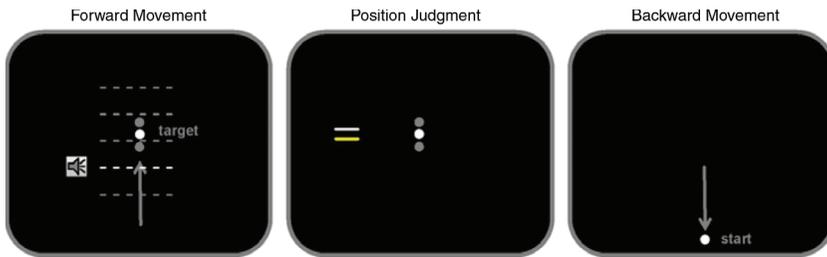


FIG. 2. Basic procedure of the present study. The participants were asked to move their right hand holding a stylus from a start position in the direction of a target position and to stop the movement after they heard a tone. Then, the current target position (that was still visible) was judged by the choice of one of two comparison stimuli (i.e., lines) before the stylus was moved back to the start. There were three possible target locations (white dot indicates a currently visible target) and five possible positions at which stop signals occurred (delineated by the dashed lines). Movements were performed on a horizontal plane below a mirror that prevented vision of the hand and stylus. In Experiment A, continuous visual feedback of the stylus position was provided. In Experiment B, in contrast, the current position of the stylus was not visible during the forward movement.

Experiments A and B differed only in visual feedback accompanying forward movements of the stylus. In Experiment A, the current stylus position was continuously presented during the forward movement (green dot, 2 mm in size). Note, however, that after the movement stopped (i.e., before the position judgment), the feedback disappeared. In Experiment B, forward movements were performed in the absence of visual feedback. In both experiments, the current stylus position was displayed during the backward movement when the y -distance between the stylus and the start position fell below 38 mm.

There were three possible target positions. Related to the y -coordinate, the target was located either approximately in the middle between the two comparison lines (middle target), 0.76 mm above the further line (far target), or 0.76 mm below the closer line (close target). That is, the distance between the start and the comparison stimuli was constant (149.72 and 151.24 mm), whereas the start-target distance varied (148.96, 150.48, and 152 mm). This stimulus configuration ensured that the task was not too easy for the participant, and thus offered the possibility to capture a possible effect of movement amplitude on location estimates.

The distance at which the stop signal occurred (related to the y -coordinate) was varied so that the stylus movement could be stopped from substantially before the target, via near the target, and through substantially behind the target. This stop distance was chosen based on previous similar experiments (unpublished) and amounted to 90.44, 115.52, 140.60, 165.68, and 190.76 mm. It took into account an expected delay between the stop signal and the endpoint of the movement. As shown in the Appen-

dix, this manipulation was successful. That is, the participants stopped the movement near the target in the middle stop condition and successively further away with an increase and a decrease in stop distance.

The experiments included thus two independent variables: target position (3 levels) and stop distance (5 levels). Each experiment consisted of three blocks with 60 trials each.⁵ In each block, each combination of target position and stop condition was presented four times in a randomized order. At the beginning of each experiment the participants performed eight practice trials, which were not included in the analyses.

Data Pre-processing, Dependent Variables, and Analyses

Trials in which movement amplitude was below or above 2 standard deviations of the median as computed for each participant, each target, and each stop condition were excluded from analysis. This outlier procedure served to improve the intended manipulation of movement amplitude. Overall, 95.1% (Experiment A) and 95.0% (Experiment B) of trials entered the analyses.

The primary dependent variable was the percentage of choices of the further comparison stimulus. These percentage values were transformed to arcsine values (e.g., Sokal & Rohlf, 1981) and were then analyzed using an analysis of variance (ANOVA) with target position and stop distance as within-subjects factors.

Besides measuring judgment behavior, some movement parameters indicating motor planning and control strategies were also accessed. "Movement amplitude" was measured as a difference between the y -coordinate of the start position and the y -coordinate of the stylus after pressing the stylus key following the stop signal. "Movement time until the stop signal" was defined as a time difference between defined movement onset (exceeding 5.7 mm⁶ in respect to the start position) and the time at which the stop signal was presented. "Reaction time after stop signal" was the interval between the onset of the stop signal and the pressing of the stylus key.

These parameters can be considered as complementary in the present context and are indicative of current movement-planning processes. Planning a far movement is typically associated with a larger force impulse than planning a shorter movement (e.g., Gordon & Ghez, 1987; Messier & Kalaska, 1999). Accordingly, movement times before the stop signal in a given trial should be longer for movements that are planned relative to a closer endpoint. Also, stopping a movement planned relative to a far endpoint can

⁵One participant of Experiment B completed four instead of three blocks. Excluding this participant from the analyses did not change the results substantially.

⁶This value seemed appropriate in the present context because it reduced an effect of possible small deviations of the stylus from the start position before target movement.

be assumed to be more difficult. Thus, the reaction time after the stop signal as well as the current movement amplitude can be assumed to increase for movements planned according to a far endpoint as compared with movements planned according to a close endpoint.

According to this rationale, all three parameters basically capture the velocity of the movement, which depends on the preprogrammed force. In theory, online control processes can also contribute to these measures. This, however, would not substantially limit the conclusions relating to the question of interest (see below).

An initial analysis was designed to detect possible adjustments of current motor behavior depending on the previous trial. For this purpose, two closer and two further stop conditions were pooled,⁷ and the selected movement parameters were averaged according to whether the stop categories were repeated or switched in successive trials. Then, ANOVAs including target position, movement type (i.e., stop category), and trial type (repetition, switch) as factors were performed for each movement parameter.

Subsequently, a correlation analysis was performed to test whether such motor adjustments were due to the judgment behavior observed in the previous trial as suggested by action-specific accounts of perception (see the Introduction). For this purpose, partial correlations were computed between movement amplitudes of subsequent trials by using target distance in trial $n-1$, stop distance, and target distance in Trial n as control variables. This analysis was performed for each participant and captured (similarly to the initial ANOVA approach, see above), an effect of movement amplitude of a previous trial ($n-1$) on movement amplitude in a given trial (n). In other words, the analysis aimed to assess the current variability in movement amplitude not due to the conditions of the current trial but due to the movement variability of the previous trial. It was assumed that if judgment in a previous trial prompts the motor behavior in a current trial, these correlations should vanish when judgments in trial $n-1$ are included as an additional control variable.

RESULTS

The main results are shown in Fig. 3 and the Appendix. An increase in target distance resulted in an increase in the preference of the further comparison stimulus. An ANOVA including target position and stop distance as factors revealed a significant main effect of target position for Experiment A ($F_{2,46} = 112.08$, $p < .001$, $\eta_p^2 = 0.83$) and for Experiment B ($F_{2,48} = 59.28$, $p < .001$, $\eta_p^2 = 0.71$). More importantly, an increase of movement extent was

⁷Here, the middle stop condition was excluded from the analyses. Note, the effect of this condition is still present in the data (of switch trials). This effect, however, can be assumed to be comparable for the closer and further stop categories.

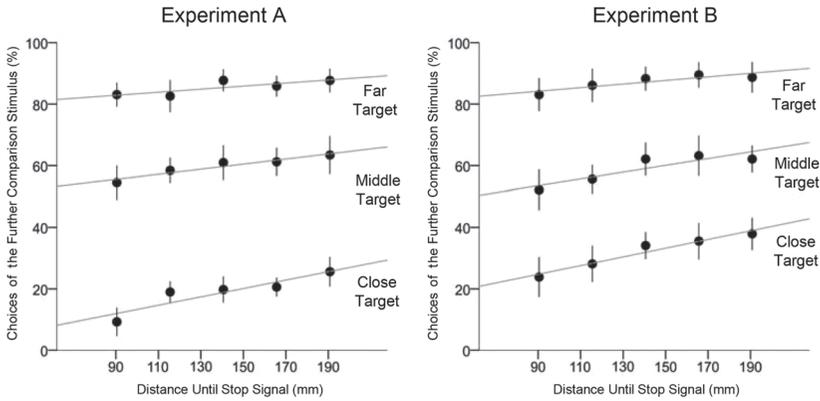


FIG. 3. Percentage choices of the further comparison line for the three targets and five movement conditions (untransformed). Error bars reflect within-participants confidence intervals (95%) computed according to Cousineau (2005).

associated with an approximately linear increase in the preference of the further comparison stimulus, as predicted. That is, the participants judged the target stimulus as further away the larger the amplitude of the preceding movement was. A significant main effect of stop distance was observed for Experiment A ($F_{4,92} = 4.15, p = .004, \eta_p^2 = 0.15$), as well as for Experiment B ($F_{4,96} = 3.70, p = .01, \eta_p^2 = 0.13$). There were no significant interactions ($p > .08$). Moreover, a linear contrast of the factor stop distance was significant in both experiments ($F_{1,23} = 6.92, p = .02, \eta_p^2 = 0.23$ and $F_{1,24} = 5.02, p = .04, \eta_p^2 = 0.17$).

Figure 4 shows movement amplitude, movement time until the stop signal, and the reaction time after the stop signal as a function of pooled stop distance in the current and in the previous trial. Movement amplitude was shorter after short than after large movements. Movement time until the stop signal, in contrast, tended to increase after short movements. Reaction times after the stop signal in a given trial tended to be faster when short movements were performed in a preceding trial.⁸ The ANOVAs including target position, movement type (i.e., stop category), and trial type (repetition, switch) as factors yielded a significant interaction between movement type and trial type for movement amplitude (Experiment A: $F_{1,23} = 13.39, p = .001, \eta_p^2 = 0.37$; Experiment B: $F_{1,24} = 9.63, p = .01, \eta_p^2 = 0.29$), for the movement times (Experiment A: $F_{1,23} = 22.98, p < .001, \eta_p^2 = 0.50$; Experiment B: $F_{1,24} = 13.00, p = .001, \eta_p^2 = 0.35$), and for the reaction

⁸For far movements, this effect disappeared in Experiment A and was reduced in Experiment B (see Fig. 4). This slight deviation from the overall pattern might be related to a type of ceiling effect because the probability of stopping increased with an increase in stop distance. In a similar vein, a smaller difference in movement times for short movements as compared with far movements might be due to a type of floor effect.

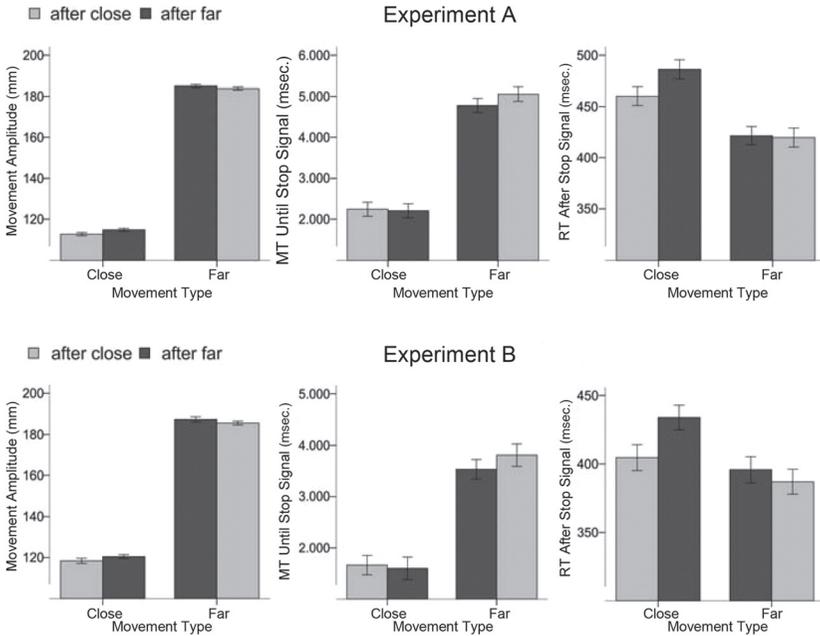


FIG. 4. Movement amplitude (left), movement time until the stop signal (middle), and reaction time after the stop signal (right) depending on whether the previous trial contained the same or a different stop category. Error bars reflect within-participants confidence intervals (95%) computed according to Cousineau (2005).

times (Experiment A: $F_{1,23} = 5.69, p = .03, \eta^2_p = 0.20$; Experiment B: $F_{1,24} = 18.84, p < .001, \eta^2_p = 0.44$). These results suggested that the participants planned a smaller/larger movement when a preceding movement was rather small/large. Thus, changes in target perception following the variation of movement amplitude seemed to go along with adjustments of the planning and control of the subsequent movement.

To further examine such a possible relationship, correlations of the movement amplitude in trial n were initially run with movement amplitude in trial $n-1$, while target distance in trial $n-1$, stop distance and target distance in trial n served as control variables. Mean correlation coefficients observed in Experiment A and Experiment B were positive and significantly different from zero (Experiment A: $r = .16, t_{23} = 9.13, p < .001$; Experiment B: $r = .19, t_{24} = 9.03, p < .001$). Then, judgments in trial $n-1$ were included as an additional control variable. The correlation coefficients did not substantially change and were not significantly different from those observed in the initial analysis (Experiment A: $r = .16, t_{23} = 0.33, p = .74$; Experiment B: $r = .20, t_{24} = 0.81, p = .43$). These results thus suggested that adjustments of

motor behavior in a subsequent trial following varying movement amplitude in the previous trial were unaffected by the participants' judgment made in the previous trial.

DISCUSSION

The present study showed that visual targets were judged as being located further away the larger the amplitude of a concurrent arm movement was. This result extended previous findings and suggested that visual perception of object location is codetermined by the extent of currently executed hand movements. This outcome is further evidence for a close relation between perception and action as suggested by several researchers from different domains (e.g., Jordan, 1998; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Nijhawan, 2002; Müsseler & van der Heijden, 2004; Proffitt & Linkenauger, 2013).

The specific mechanisms involved in the present and similar tasks are not yet clear. The results suggest that some motor information related to the hand movement and visual signals are integrated at a certain stage of processing. However, which motor variable, e.g., might be capable of affecting the judgment of target location was not examined in the present study. Previous research indicated that final arm position (or posture, Kirsch & Kunde, 2013a) as well as shifts of spatial attention accompanying movement planning and control (Bocianski, *et al.*, 2010; Müsseler & Tiggelbeck, 2013; Kirsch, 2015) are suitable candidates to fulfill this function.

One important feature ascribed to actions' effects on perception is their adaptive function that consists in preparation for a potential action by signaling opportunities and costs associated with that action (e.g., Proffitt, 2006; Witt, 2011). This study provided no evidence for such adaptive changes. It was observed, however, that action execution in a given trial affected action execution in the next trial, but these correlations did not change when changes in perception were taken into account. Perhaps such changes were in fact not very adaptive under the conditions studied here, given that the movement was externally stopped at varying locations. In other words, changes of action planning that are mediated by altered perception might occur with more stable action requirements. Consider, e.g., a walker experiencing an increase in perception of walking distance while wearing a heavy backpack. Deciding to walk this (subjectively rather large) distance might prompt the mobilization of additional resources to safely reach the target place.

These conclusions should be considered with caution. Since the endpoint of the movement did not correspond with the visual position of the target in most cases, an assumption of a type of direct mapping between movement and visual signals might be not appropriate. Instead, an interaction on a rather abstract cognitive level may possibly explain the results. For example, the variation of movement amplitude might have been accompa-

nied by differences in the activation of concepts such as “far” and “close.” These concepts might have affected perception, rather than some low-level processes related to movement planning and control. Alternatively, the results can be indicative of an effect of motor variables on judgment behavior rather than on perception (e.g., Firestone, 2013). The present experiments cannot overcome these limitations. Accordingly, more research is needed to tackle these rather complex issues and to better understand the nature of motor effects in perceptual tasks.

To sum up, the present study demonstrated that movement extent affects the perception of visual locations. Moreover, the results showed that following perceptual changes the behavior is adjusted consistent with the direction of the presumably changed perception. There were, however, no indications that changes of perception prompt subsequent changes of action planning in the present experimental setup.

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APPENDIX

MEAN MOVEMENT AMPLITUDE (MM) IN EXPERIMENTS A AND B

	Distance Until Stop Signal									
	90.4 mm		115.5 mm		140.6 mm		165.7 mm		190.8 mm	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Experiment A										
Close target	102.6	4.8	124.9	3.5	147.1	2.1	172.2	1.9	196.4	1.7
Middle target	102.5	4.7	125.4	3.8	147.2	2.2	172.1	2.2	196.2	1.6
Far target	102.8	4.6	125.2	3.2	147.7	2.3	172.1	1.9	196.1	1.6
Experiment B										
Close target	109.8	6.1	129.9	4.7	151.7	4.6	174.2	3.5	198.1	3.2
Middle target	108.9	6.3	130.1	5.2	151.4	4.6	174.3	3.3	198.4	3.6
Far target	110.0	6.4	130.1	4.9	151.4	3.9	174.2	4.1	198.1	3.4