7 Action planning affects spatial localization

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Abstract. When observers are asked to indicate the final position of a moving stimulus, their localizations are reliably displaced beyond the final position, in the direction the stimulus was traveling just prior to its offset. Recent experiments indicate that these localization errors depend on whether or not observers track the moving stimulus with eye-movements. If they track, there is a localization error; if not, the error reduces to zero. The present series of experiments investigated whether localization error might be due, in part, to the binding of the moving stimulus in an action plan. Experiment 1 utilized circular stimulus trajectories, and the eye tracking/ no-tracking discrepancy revealed in previous studies was replicated. Experiment 2 required central fixation by all observers, and either the computer program (i.e. induction) or a button press by the observer (i.e. intention) produced the stimulus offset. The localizations made in the Intention condition were further in the direction of the planned action effect than those made in the Induction condition. Experiment 3 demonstrated these differences to be due to the intention to stop the stimulus, not the button press. And Experiment 4 revealed that action planning has its binding effect on the localization error for a duration that extends beyond the actual moment of action execution. In light of these data, an approach to perception–action coupling is proposed in which spatial perception and spatially directed action are modeled, not as input and output, respectively, but rather, as synergistically coupled control systems.

When observers are asked to indicate the final location of an apparently moving, or moving stimulus, the indicated location is reliably displaced beyond the final location, in the direction the target was traveling just prior to its offset (Finke, Freyd, and Shyi 1986; Freyd and Finke 1984; Hubbard 1995). In addition, the magnitude and direction of the displacement varies in a manner that is consistent with the laws of physics (i.e. velocity, friction, gravity; Hubbard 1995). Accounts of these errors are often conceptualized in terms of representational momentum—the notion that the dynamics of the external environment have been internalized into the dynamics of cognitive representational systems. Given that internal representations, just as external events, have dynamic properties that cannot simply be brought to a halt upon stimulus offset, dynamic representational transformations are assumed to continue for some time following stimulus offset. It is the momentum of these representations that is assumed to underlie the resulting localization error.

Implicit in this account of localization error is the assumption that the actions produced by observers during stimulus movement do not influence the processes underlying the error. In short, action processes and representational momentum processes are assumed to be independent, and the localization error is described as a post-perceptual cognitive phenomenon. Contrary to this assumed independence, the purpose of the present paper is to present a series of experiments that test whether or not the actions produced in relation to a moving stimulus contribute to the spatial distortion manifested in the localization error. These experiments are motivated by the following: (1) data that indicate the localization error may, in part, be due to the action planning required to maintain an ongoing relationship between action and stimulus motion (i.e. action control), and (2) data that indicate that perception and action-planning share common mechanisms (i.e. common neural

mediation). Collectively, these data imply that the very act of planning an action in relation to a stimulus event serves to transform the processes underlying perceptual mappings of that stimulus event. In short, it implies that action planning influences the localization error.

7.1 Action control and localization error

In representational momentum paradigms, observers are free to move their eyes. In fact, in most experiments no instruction is given in this regard, and it is assumed that eye-movements used to pursue and track the target do not contribute to the localization error. It has been demonstrated, however, that the eyes continue to drift in the direction of target motion if a pursued target, travelling on a linear trajectory, suddenly vanishes (Mitrani and Dimitrov 1978), and the magnitude of such drift varies directly with tracking velocity (Mitrani, Dimitrov, Yakimoff, and Mateeff 1979). In addition, static stimuli presented in the periphery are localized closer toward the fovea than they actually are (*foveal bias*; e.g. Müsseler, Van der Heijden, Mahmud, Deubel, and Ertsey 1999; O'Regan 1984; Osaka 1977; Van der Heijden, Müsseler, and Bridgeman 1999). In light of these data, it may be the case that when a moving target suddenly disappears, the eyes overshoot the final position of the stimulus, such that the fovea is shifted into the direction of motion. Subsequently, the foveal bias inherent in static localizations, coupled with the changing position of the fovea due to overshoot, causes the final position of the target to be localized in the direction of the fovea's motion (i.e. in the direction of the target's motion). In short, it may be the case that the localization error is related to eye-movement control.

To test this idea, Kerzel, Jordan, and Müsseler (in press) conducted a representational momentum experiment in which they asked observers to localize the final position of a moving stimulus. Unlike other representational momentum experiments, however, they devised a condition in which observers were instructed to fixate a stationary fixation point during the presentation of the moving stimulus. This instruction, of course, prevented observers from making the smooth-pursuit movements observers normally make during such tasks. The results are depicted in Fig. 7.1. In the tracking condition, in which observers were allowed to track the moving stimulus, the traditional representational momentum effect was obtained. Localizations were displaced beyond the vanishing point, in the direction of stimulus motion, and the magnitude of the localization error varied directly with the velocity of the moving stimulus. In the fixation condition, however, there was no displacement in the direction of stimulus motion. There was vertical displacement, probably due to the retinal eccentricity of the vanishing point (i.e. the fixation stimulus was located 2° below the trajectory of the moving stimulus), but there was no horizontal localization error whatsoever.

These data strongly imply that the localization errors reported in previous representational momentum experiments may have been due, in part, to the control of the eye movements necessary to track the moving stimulus. To be sure, arguments against an eye-movement account have been posed on many occasions (see Kerzel *et al.*, in press, for a thorough review of these arguments). These arguments tend to treat the moving eye as a moving camera, however, and they do so by downplaying the fact that oculomotor tracking is a controlled action. Given the data of Kerzel *et al.*, it seems this latter point is rather central to the localization error, and really cannot be downplayed. Oculomotor control requires planning, and this planning must (1) take into account anticipated future locations of the moving stimulus, and (2) be generated continuously in order to effectively control eye–target relationships. In light of these demands on eye-movement control, it may be the
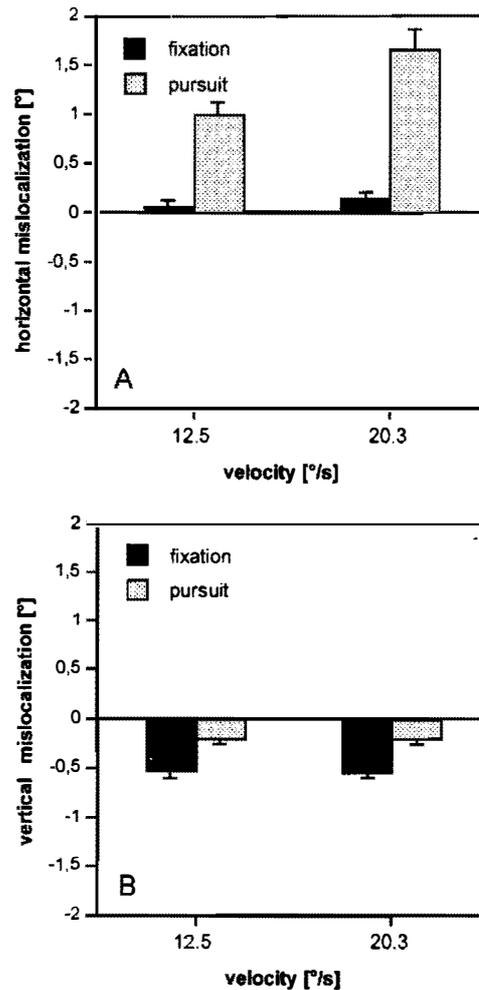
Fig. 7.1 Mislocalization as a function of instruction (pursuit vs. fixation) and velocity. The dark bars represent the Fixation condition, and the light bars, the Pursuit condition. Error bars represent standard errors between participants. *Panel A*: Positive values indicate errors in the direction of movement, negative values errors opposite to the direction of movement. *Panel B*: Positive values indicate errors above the final position, negative values errors below the final position.

case that the localization error is more due to momentum derived from action control than momentum derived from action-independent post-perceptual representations.

7.2 Action planning and perceptual mapping

Another challenge to the idea that localization errors are action independent derives from data that reveal rather tight functional couplings between the planning aspect of action control and shifts in spatial perception. Classic research in visual attention, for example, indicates that roughly 50–100 ms after the presentation of a saccadic target, the threshold for the detection of events at the

target's position is reduced (Bachmann 1999; Klein 1988; Posner 1980; Posner and Cohen 1984; Schneider and Deubel, this volume, Chapter 30; Wolff 1999). Such pre-saccadic shifts in detectibility thresholds constitute shifts in the spatial content of perception that are associated with the planning of an action. Some researchers even argue that these shifts constitute a necessary pre-condition of saccadic control (Rizollatti, Riggio, Dascola, and Umiltà, 1987; Wolff 1999).

Further evidence of planning-perception coupling comes from experiments in which observers are asked to make judgments about the perceived location of a stimulus presented during the production of an action. Dassonville (1995), for example, asked observers to move their arm through the dark and localize the point at which their moving finger received a vibrotactile stimulus. Observers tended to localize the stimulus at locations beyond the point of stimulation. In other words, observers perceived the stimulus at locations to which they were planning to move their hand at the moment the stimulus was presented.

Collectively, these data indicate a rather tight functional coupling between action planning and perceptual space. To be sure, this idea is not completely new. Both philosophers and psychologists have argued that actions are planned in terms of the distal effects they are to produce (i.e. in terms of distal perceptual space). Harless, for example (see Hommel 1998), referred to intentions, or action plans, as Effektbilder (effect images). James (1890/1950, p. 501) said, '. . . an anticipatory image . . . is the only psychic state which introspection lets us discern as the forerunner of our voluntary acts.' And Hershberger (1976, 1987, 1998), in an attempt to explicate the idea that actions are planned in terms of their distal effects, referred to action plans as 'afference-copies' in order to contrast them with von Holst and Mittelstaedt's (1950) concept, 'efference copy'.

This idea has recently received a more formal theoretical/empirical treatment in what is known as the theory of Common Coding (Prinz 1992, 1997). Basically, this theory assumes that (1) actions are planned in terms of their distal consequences, and (2) the planning of an action necessarily recruits, or rather presses into service, neural transformations that also mediate the perception of those distal consequences. Empirical support for this idea derives from both neurophysiological and psychophysical research. Several neurophysiological findings of the last decade, for example, point to populations of neurons that seem to mediate both *sensitivity to*, and *production of*, distal events (i.e. they appear to be involved in both perception and action planning, respectively). Examples include the 'visual-and-motor neurons' (e.g. Taira, Mine, Georgopoulos, Murata, and Sakata 1990) found in monkey parietal cortex, and the 'mirror neurons' (e.g. di Pellegrino, Fadiga, Fogassi, Gallese, and Rizzolatti 1992) located in the premotor cortex. Additional neurophysiological support for common coding derives from research on neural mechanisms that accomplish *coactivation* of distributed brain areas (Roelfsema, Engel, König, and Singer 1997).

Psychophysical support derives from studies in which participants are asked to identify the spatial value (i.e. left or right) of an arrow stimulus that is briefly presented while participants plan either a left or right button press (for an overview see Müsseler 1999; Müsseler and Wühr, this volume, Chapter 25). These studies reveal that observers are better able to identify (i.e. perceive) the direction of the arrow stimulus if it is presented alone, versus in the midst of an action plan (see also comparable findings by De Jong 1993; De Jong and Sweet 1994; Jolicœur 1999). Further, if the arrow is presented in the midst of an action plan (i.e. it is presented while observers are planning a right or left button press), its direction is better identified if it is opposite that of the planned action (e.g. left-pointing stimulus arrow presented during the planning of a right keypress). Common coding asserts these effects occur because the spatial content of planning the right or left button press becomes bound in the action plan and is, thus, less available for mediating

perception of the arrow's direction (i.e. right or left). In short, the spatial dimension of planning one event interferes with the perception of another.

Though these studies address the spatial relationship between planning one event and perceiving another, they do not address whether or not an action-plan involving a particular stimulus influences the perceived spatial location of that stimulus. This is, of course, the issue being addressed by the present paper. If spatial perception and action planning share common mediation, the perceived location of a stimulus should depend on whether or not the stimulus is bound in an action plan. In short, the localization error may be due to the action-planning aspect of action control.

The data of Kerzel *et al.* (in press) seem to address this issue—localization errors were found in the Pursuit condition but not in the Fixation condition. One might assume these differences in localization were due to the binding of the moving stimulus in an action plan in the Pursuit condition (i.e. 'track the moving stimulus'). It is not clear, however, whether the localization error resulted exclusively from the planning of the eye movements. If localization is influenced by action planning *per se* then localizations should vary as a function of action plans, regardless of the effector specified in the action plan. We devised a series of experiments to address this issue. Specifically, observers were asked to indicate the perceived final location of a target that moved on a circular trajectory around a central fixation point. Circular trajectories were utilized, as opposed to linear trajectories, in order to control for the retinal eccentricity of the point at which the stimulus disappeared. Experiment 1 constituted a replication of the Kerzel *et al.* experiment. In Experiment 2, the offset of the moving stimulus was produced by either an observer-initiated button press (i.e. the Intention condition), or the computer program (i.e. the Induction condition). These two conditions were designed to test whether the relationship between action planning and localization error is specific to oculomotor control, or extends to action control in general. Experiment 3 was a replication of Experiment 2, save for a cue condition in which observers were instructed to press a button in response to the onset of the moving stimulus. This experiment was devised to clarify whether any localization differences between the Induction and Intention conditions in Experiment 2 were due to the fact that participants pressed a button in the Intention condition, yet did not do so in the Induction condition. Finally, Experiment 4 was devised to test just how long action planning has its binding effect upon perceptual space. To test this, we ran three versions of the Intention condition, each of which was programmed to produce a different degree of delay between the observer's button press and the actual offset of the moving stimulus.

7.3 Experiment 1: oculomotor action plans

The purpose of Experiment 1 was to determine whether a difference in oculomotor action plans (i.e. fixation versus tracking), relative to the moving target, would produce differences in localization scores regarding the target's final position. This constituted a replication of Kerzel *et al.* (in press), save for the use of circular versus linear target trajectories.

7.3.1 Method

7.3.1.1 Participants
Seven female and five male students of the University of Munich who ranged in age from 21 to 32 years (mean age of 26 years) were paid to participate in the experiment. They reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

7.3.1.2 Apparatus and stimuli

The experiment was controlled by a Macintosh computer. The stimuli were presented on a 17 inch monitor with a refresh rate of 75 Hz and a luminance of approximately 40 cd/m^2 with black-on-white projection. The rest of the room was dimly lit. The participant's head was placed on a chin and forehead rest 500 mm in front of the monitor.

The moving stimulus was a dot, the size and luminance of which were 4.35 mm (0.5°)[1] and 13 cd/m^2, respectively. On each trial, the dot traced out a trajectory that circled a fixation cross at a radius of 48 mm (5.5°, cf. Fig. 7.2). The stimulus movement was induced by shifting the dot 0.54° or 2.15° clockwise with every vertical retrace of the monitor (13 ms per frame), resulting in two possible tangential velocities; 3.85 °/s (33.7 mm/s) and 15.4 °/s (134.6 mm/s). These target velocities were well-within the velocity range in which observers can accurately track a moving target (Robinson 1968). The movement started at the upper portion of the circle (in the range of 20° before and 20° after the 12 o'clock position). Movement length varied from 90° to 360° with absolute movement times of 2240 to 8960 ms for the slow velocity and 560 to 2250 ms for the fast velocity.

An adjustment cursor, which was identical to the stimulus, appeared 500 ms after stimulus-offset at a random position on the circle. It could be moved either clockwise or counterclockwise along the circle's edge by pressing a right or a left button, respectively. Each button press resulted in a 0.13° change in the adjustment cursor's position. In order to accelerate the adjustment process, the adjustment cursor's velocity accelerated if the button was pressed for a longer duration. Thus, a complete circle required approximately 1500 ms. Buttons were mounted on a flat board in front of the participant.

7.3.1.3 Design and procedure

The four combinations of two instructions (pursuit eye movement and fixation) and two velocities were presented blockwise. The order was counterbalanced between participants. In the Pursuit condition, participants were instructed to follow the stimulus with their eyes until it vanished, while in the Fixation condition they were instructed to fixate the fixation cross during the presentation of the moving stimulus.

Participants experienced 24 repetitions of each cell of the 2 × 2 within-subject design (i.e. 96 trials overall). The experiment lasted approximately 30 min, including training trials and short breaks.
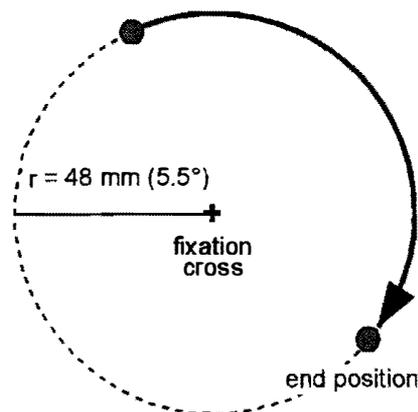

Fig. 7.2 Stimulus configuration used in the present experiments. The moving stimulus circled the central fixation cross at a radius of 5.5°.

7.3.2 Results and discussion

The localization score on every trial was computed as the difference between the computer-indicated and participant-indicated final position of the stimulus with respect to movement direction. Positive values indicate localizations beyond the target's final position.

Mean localization errors were computed separately for every participant and each condition. A 2×2 repeated measures analysis of variance (ANOVA) with the factors instruction (pursuit vs. fixation) and velocity (3.75°/s vs. 15.4°/s) revealed a significant difference due to instruction, $F(1, 11) = 69.08$, MSE $= 8.34$, $p < 0.001$. Figure 7.3 depicts these effects. In the Fixation condition, a *post-hoc* Scheffè test revealed significant negative localization errors (15.4°/s: -4.95 mm, $p < 0.01$; 3.75°/s: -3.59 mm, $p < .05$), while in the Pursuit condition, in combination with the fast velocity, there was a significant positive localization error of 4.20 mm, $p < 0.01$. Moreover, there was a significant interaction between instruction and velocity, $F(1, 11) = 9.91$, MSE $= 6.01$, $p = 0.009$. The amount of error increased in both directions with faster velocity.

Basically, Experiment 1 replicated the results from Kerzel *et al.* (in press). As can be seen in Fig. 7.3, the moving target's vanishing point was localized significantly further in the direction of target motion in the Pursuit versus the Fixation condition. In addition, faster-moving stimuli were localized further in the direction of target motion than slower-moving stimuli in the Pursuit condition, but not in the Fixation condition. However, in contrast to the results of Kerzel *et al.* (in press) the Fixation condition revealed a reliable negative localization error (i.e. an error in the direction opposite the movement direction of the target). Negative localization errors have been previously reported in tasks requiring localization of either (1) the initial target position (Actis Grosso, Stucchi, and Vicario 1996; Thornton 2001) or (2)—with an accompanying flash—the final position (Müsseler, Stork, and Kerzel 2001). A possible explanation of this negative error is that, in the Fixation
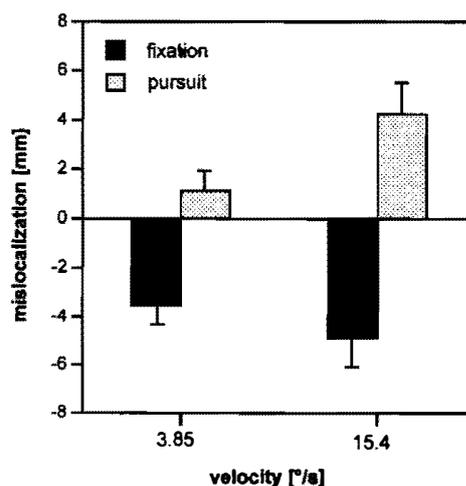
Fig. 7.3 Mislocalization as a function of instruction (pursuit vs. fixation) and velocity. The dark bars represent the Fixation condition, and the light bars, the Pursuit condition. Positive values indicate errors in the direction of movement, negative values errors opposite to the direction of movement. Error bars represent standard errors between participants.

condition, retinal stimulation during one refresh rate overlaps with the stimulation of the previous refresh rate(s). As a consequence, it is possible for stimulation to build up, simply as a function of the stroboscopic nature of stimulus presentation on a computer screen. Summation of stimulus information (cf. also the Bunson–Roscoe law) caused by stimulation during successive frames may occur at all positions on the stimulus trajectory, save the final position. Given such summation, it may be the case that stimulation is less pronounced and consequently more often missed at the final position. Preliminary results from our laboratory support this idea. In the present context, however, we are less concerned with negative localization error than we are with the differences in localization error between the Fixation and the Pursuit conditions. In short, the data indicate that the action control required in the pursuit condition gave rise to localization errors that were further in the direction of stimulus motion than those obtained in the Fixation condition. Experiment 2 was devised to determine whether or not it was the action planning aspect of action control that gave rise to these differences.

7.4 Experiment 2: effector-independent effects of action planning

Given the results of the previous experiment, Experiment 2 was designed to determine whether the pattern of localizations is specific to oculomotor control. To test this, we repeated Experiment 1, and varied the action plans participants were to generate. In the Intention condition, participants fixated the central fixation cross throughout the presentation of the moving stimulus, yet were instructed to stop the stimulus' motion via a button press. In the Induction condition, participants fixated the central fixation cross throughout the presentation of the moving stimulus, and the offset of the stimulus was caused by the computer program, not the participant. This is similar to the Fixation condition of Experiment 1. If the act of binding a stimulus in an action plan contributed to the localization differences revealed in Experiment 1, then localizations made in the Intention condition should differ from those made in the Induction condition. This is because the action plan generated in the Intention condition (i.e. stop the stimulus' motion) necessarily entails the anticipated distal action effect, that is, the location of the target at the moment the button is pressed. This is not the case in the Induction condition. Due to common mediation, this anticipatory aspect of the Intention condition should alter perceptual space in an intention-relative manner, thus producing localization differences between the two conditions.

To be sure, the pattern of results in Experiments 1 and 2 are not expected to be exactly the same. This is because of differences in the action plans required by the two experiments. In the Pursuit condition of Experiment 1, the task was to track the target via eye movements. In the Intention condition of the present experiment, the task was to stop the stimulus' motion. Both tasks require action planning that takes into account anticipated future locations of the moving stimulus, but they differ in terms of the anticipation required. The Pursuit condition required continuous anticipation due to the need for continuous tracking. The Intention condition, on the other hand, only required anticipation and planning regarding the stimulus' final location (i.e. vanishing point). Thus, while the continuous anticipation required by the Pursuit condition gave rise to positive localization error, the rather discrete anticipation required of the Intention condition is not expected to give rise to positive localization error (i.e. the localizations should be more accurate).

7.4.1 Method

7.4.1.1 Participants
Six female and four male students of the University of Munich who ranged in age from 21 to 34 years (mean age of 25.4 years) were paid to participate in the experiment.

7.4.1.2 Apparatus and stimuli
All was the same as in Experiment 1, save for the target velocities and the presence of a response button. Given that the present experiment required participants to press a button to stop the stimulus motion in the Intention condition, we utilized the faster of the two velocities from Experiment 1 (i.e. 15.4°/s) as well as a new, faster velocity (30.8°/s, i.e. 269.3 mm/s). The faster velocity increased the salience of the action/effect relationship. In other words, faster targets approximated the more ecologically valid, natural relationship that exists between arm/finger movements and moving visual targets (e.g. swatting at a fly, deflecting a rapidly moving projectile, catching a fly ball).

Stimulus movement started at a random position on the circular orbit and stimulus offset was either controlled by the computer or by a button press of the participant. Movement length varied from 90° to 360° with absolute movement times of 560 to 2240 ms for the slow velocity and 280 to 1120 ms for the fast velocity.

7.4.1.3 Design
The two task conditions (Intention vs. Induction) were presented blockwise. Half the participants started with the Induction condition. The two velocity conditions varied randomly within each block. There were 10 blocks of 10 trials. Thus, each participant experienced 25 repetitions of each of the four unique experimental conditions.

7.4.1.4 Procedure
In the Induction condition the offset of the moving stimulus was produced by the experimental program. In the Intention condition the participant was instructed to press a button with the right index finger in order to stop the target's motion. Participants were instructed to stop the movement at an arbitrary point after the stimulus had moved 90°, yet before it had moved 360°. They were also instructed that over trials they should distribute the stop positions between 90° and 360° and should not choose recurrent salient positions (e.g. the 6 o'clock position). If a participant pressed the button too early or too late, an error message was presented, and the trial was repeated immediately.

7.4.2 Results and discussion

Mean localization scores were computed separately for every participant and each condition. These scores were then entered into a 2×2 ANOVA with the factors instruction (Intention vs. Induction) and velocity (15.4°/s vs. 30.8°/s). As can be seen in Fig. 7.4, there was a significant main effect due to instruction, $F(1,9) = 5.68$, MSE $= 8.75$, $p = 0.041$, and a tendency towards an interaction $F(1,9) = 3.86$, MSE $= 11.72$, $p = 0.081$. The Scheffé test revealed that the significant effect of instruction was due to differences between the Fast-Induction condition and the Fast-Intention condition ($p < 0.05$).

The data are consistent with an action-planning account. The localization errors made in the Intention condition were significantly further in the direction of stimulus motion than those made in the Induction condition; that is they were more accurate especially at the faster velocity. These data
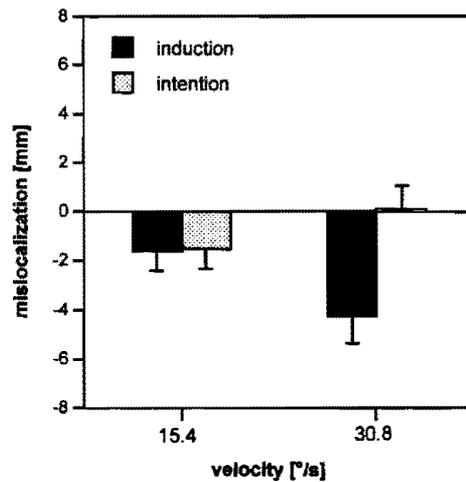
Fig. 7.4 Mislocalization as a function of instruction (intention vs. induction) and velocity. The dark bars represent the Induction condition, and the light bars, the Intention condition.

indicate that action planning exerted an influence on the perceived location of the stimulus even though the action used to attain the planned effect was a button press, not an eye movement. This finding is also telling, in that the spatial location of the action (i.e. the location of the button press) and the location of the event specified in the action plan (i.e. the position of the moving stimulus) did not spatially overlap—the two were located at different spatial locations. These data support the assertion of the action-planning account that due to the common mediation of perception and action planning, the planning of an action recruits the transformations to be used in the perception of the planned distal event. In the present case, the binding of the target's final location within a button-press action plan (i.e. 'stop the stimulus motion by pressing the button') shifted the localization in the direction of the intended effect.

7.5 Experiment 3: action-independent effects of action planning

Given the findings thus far, one might claim that the localization differences revealed in Experiment 2 were due to the fact that participants produced a button-press action in the Intention condition, but not in the Induction condition. If it was action planning *per se*, not only action production, that was responsible for the differences, then different action plans that utilize the same action should produce different localization patterns. We devised an experiment to test this idea. In one condition (the Cue condition) participants pressed a button in response to the onset of the moving stimulus, while in another (the Intention condition) participants pressed a button in order to produce stimulus offset. If the action plan is truly critical to the localization error, then localizations made in the two conditions should not be the same. In the Cue condition, the action plan refers to the initial stimulus location, while in the Intention condition, it refers to the final stimulus location. In both conditions, the offset of the moving stimulus was produced by the participant's action (i.e. the button press), but in the Cue condition the final position of the moving stimulus did not have to be bound in the participant's button-press action plan. Rather, given the instructions, all a participant had to do was react to the onset of the moving stimulus. In short, the moving stimulus constituted an action cue, and it

was the initial position of the moving stimulus, not the final position, that was relevant to, and thus, potentially bound within, the participant's button-press action plan.

If there are differences between the Cue condition and the Intention condition, however, one will not know if they are due to action planning or trajectory length, since the stimulus, simply due to instructions, traces out a larger trajectory in the Intention condition. Thus, a variant of the Induction condition of Experiment 2 was utilized in which the length of the trajectory was limited to a quarter circle. Trajectory length, therefore, was similar to that in the Cue condition, but the offset of the stimulus was produced by the computer program, not the participant.

7.5.1 Method

7.5.1.1 Participants
Eight female and four male students of the University of Munich who ranged in age from 20 to 41 years (mean age of 27.2 years) were paid to participate in the experiment.

7.5.1.2 Apparatus and stimuli
Stimulus presentation was the same as in Experiment 2, with the following exceptions. A Cue condition was added in which participants were instructed to stop the movement of the stimulus, via a button press, as soon as the moving stimulus appeared. The Intention condition remained unchanged. In order to control for trajectory length, a variant of the Induction condition was utilized in which the length of the trajectory was limited to a quarter circle.

7.5.1.3 Design and procedure
The three task conditions (Intention vs. Induction vs. Cue) were presented blockwise and their order was counterbalanced between participants. Stimulus velocities were the same as in Experiment 2, and were randomized within blocks. Overall, participants experienced 150 trials. The procedure was the same as Experiment 2. The experiment lasted approximately 35 min, including a training block.

7.5.2 Results and discussion

One participant had to be excluded from further analysis because, following the experiment, it was discovered she had followed the instructions incorrectly. Two separate ANOVAs were conducted on the Cue vs. Intention and Induction vs. Intention data. The Cue vs. Intention analysis revealed only a significant main effect of instruction $F(1, 10) = 5.95$, $MSE = 6.75$, $p = 0.035$, that is, judgments were more accurate in the intention condition (Fig. 7.5). The Induction vs. Intention analysis revealed a significant interaction, $F(1, 10) = 6.81$, $MSE = 3.47$, $p = 0.026$. Follow-up Scheffé tests revealed the interaction to be due to differences between the Induction-fast and slow conditions ($p < .01$) and the Induction-fast and Intention-fast conditions ($p < .05$). This constitutes, save for the predictability of the trajectory length in the Induction condition, a replication of Experiment 2.

Localizations made in the Intention condition were more accurate than those made in the Cue condition. If this was due solely to trajectory length, then the Cue and Induction conditions should have expressed a similar relationship to the Intention condition. This was not the case. While the Intention/Cue analysis revealed only an effect of instruction, the Intention/Induction analysis revealed an interaction. The differences between these patterns indicate that something other than trajectory length was
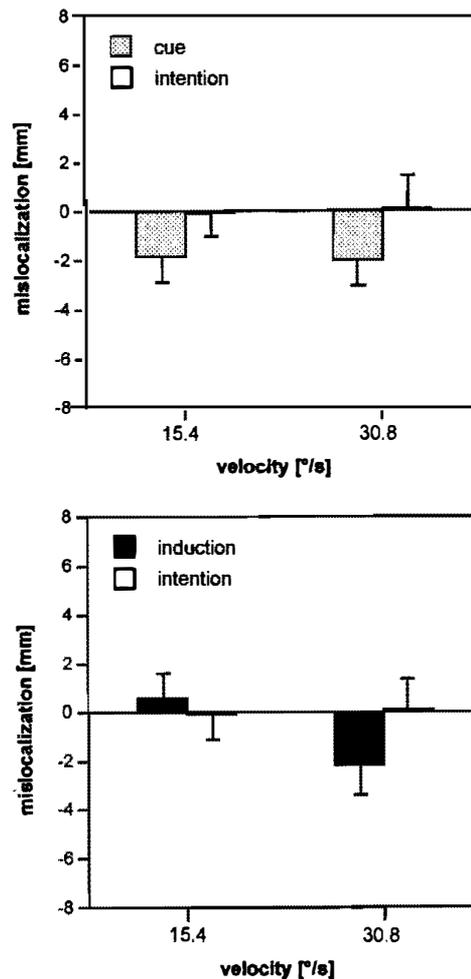
Fig. 7.5 Mislocalization as a function of instruction and velocity for the Cue–Intention data (*top*) and the Induction–Intention data (*bottom*). In the Intention–Cue graph, dotted bars represent the Cue condition, and light bars, the Intention condition. In the Induction–Intention graph, dark bars represent the Induction condition, and light bars, the Intention condition.

responsible for the differences between the Intention and Cue conditions. Specifically, in the Induction condition, the moving stimulus was not bound in an action plan. Since the trajectory length was constant (i.e. a quarter turn) and the task conditions were blocked, the final position of the moving stimulus, though not bound, may have nonetheless become predictable due to repetition, especially in the slower conditions. This may account for the differences between the Induction–fast and Induction–slow conditions. In the Cue condition, however, stimulus duration was similar to that in the Induction condition, but the initial position may have been bound in the button-press action plan. Thus, the perceived vanishing point appears to have been attracted to the location of the initial position.

Collectively, these data support the following assertions: (1) the differences between the Intention and Cue conditions were not due to trajectory length, and (2) the localization differences revealed in Experiments 2 and 3 were due to differences in action planning, not action execution, *per se*.

7.6 Experiment 4: the duration of action-relative binding

In all experiments reported so far, localizations of stimuli bound in an action plan were attracted to the location of the planned effect. In the present experiment we attempted to assess the duration of such binding. We did so by presenting observers three different versions of the Intention condition, each of which was programmed to produce a small degree of delay between the observer's button press and the actual offset of the moving stimulus. If the action plan loses its binding impact on perceptual space immediately upon action completion, localizations of stimuli having delayed offsets should not be attracted to the intended location, and there is no reason to expect the error in such localizations should vary with changes in the offset delay. If the action plan still has a binding impact on perceptual space at the moment of the delayed stimulus offset, however, the localizations should be attracted to the intended offset location, and the localization errors should vary inversely with offset delays. This is because the localizations of stimuli entailing longer offset delays would entail the growing discrepancy between intended and actual offset location.

7.6.1 Method

7.6.1.1 Participants
Six female and four male students from the University of Munich, ranging in age from 20 to 37 years (mean age of 27.5 years), were paid to participate in the experiment.

7.6.1.2 Apparatus and stimuli
Stimulus presentation in the Induction condition was the same as in Experiment 2. In the Delay conditions, stimulus offset was brought about by a participant-produced button press, as in Experiments 2 and 3, plus a pre-programmed, post button-press delay. There were three levels of delay: 0, 53 ms (4 frames), and 107 ms (8 frames).

7.6.1.3 Design and procedure
The two task conditions (Induction vs. Delay) were presented in blocks. Stimulus velocity varied randomly within both blocks, while delay also varied randomly within the delay block. Half the participants started with the Induction condition. The participants underwent 25 repetitions per cell of the 4×2 within-subjects design, for a total of 200 trials. The experiment lasted approximately 40 min, including training trials. The participants were not informed that delays were utilized in the present experiment. After the experiment participants were asked whether they had noticed the delays.

7.6.2 Results and discussion

None of the participants reported noticing the different delay conditions. A tendency towards an instruction effect resulted from a 2×2 ANOVA with the factors instruction (induction vs. intention: delay 0) and velocity, $F(1, 9) = 4.00$, MSE $= 14.44$, $p = 0.077$. This result replicated the finding of the previous experiments. A 3×2 ANOVA with the factors delay (0, 53, vs. 107 ms) and velocity (15.4°/s vs. 30.8°/s) revealed a significant effect of delay, $F(2, 18) = 7.40$, MSE $= 1.68$, $p = 0.005$. As can be seen in Fig. 7.6, the localization error varied inversely with offset delay. Note, the displacement was

determined relative to the actual offset of the moving target (not the position intended by the button press); thus, decreasing localization values represents localization towards the intended stopping point.

In sum, the data indicate that action planning has its binding impact on perceptual space for a duration that extends beyond the actual moment of action execution. Localization errors varied inversely with offset delays. This would not have been the case had the action plan lost its binding impact immediately upon action completion. Rather, the inverse relationship between localization error and offset delay indicates that the localizations were attracted toward the intended final location at all levels of delay, thus causing the localization scores to decrease as the distance between the intended and actual offset location increased. To be sure, the methodology of the present experiment only extends the binding interval 107 ms beyond the moment of action execution. Thus, further research is needed to measure the size of the interval precisely.

7.7 General discussion

When observers are asked to indicate the final location of a moving stimulus, their localizations tend to be displaced beyond the actual final location, in the direction of stimulus motion. Traditional accounts attribute this localization error to post-perceptual action-independent cognitive processes (Hubbard 1995). The present series of experiments tested this assumed independence between action processes and localization error because recent findings indicate the error may be influenced by the action-planning processes involved in action control (Kerzel, Jordan, and Müsseler, in press). In addition, research indicates that action planning affects spatial localization because action planning is mediated by processes that also mediate the perception of stimulus location. In short, perception and action planning seem to share common mediation. This notion of common mediation has received formal theoretical/empirical treatment in what is known as the Theory of Common Coding (Prinz 1992, 1997). Specifically, the theory assumes the following: (1) actions are planned in terms of their intended distal effects, (2) action planning and perception, due to their inherently distal nature, share common neural mediation, and (3) action planning produces anticipatory recruitment (i.e. binding) of the transformations mediating the perception of the intended distal effect. If this
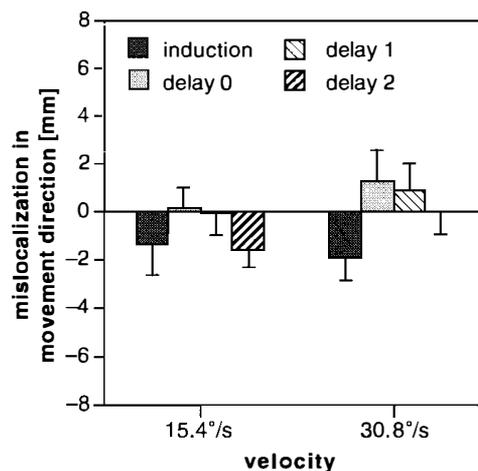
Fig. 7.6 Mislocalization as a function of instruction (intention vs. induction), velocity, and delay.

notion of common mediation is correct, then localization error is not independent of action processes. Rather, the perceived location of a stimulus should vary as a function of *whether* and *how* the stimulus is bound in an action plan. Localizations of stimulus location therefore, should be intention relative.

We began our investigation with the same type of localization task used in traditional representational momentum paradigms, save for our use of circular versus linear stimulus trajectories. In representational momentum paradigms, observers usually track the target with their eyes and, in order to do this, anticipate the future positions of the target. Given the nature of oculomotor tracking (Mitrani and Dimitrov 1978; Mitrani et *al.* 1979), we assumed that the forward bias observed in representational momentum experiments reflects a tendency to localize the target toward the anticipated locations inherent in the eye-movement action plan. Consequently, we predicted the bias would disappear in a fixation condition in which observers were not allowed to pursue the target via eye movements. Indeed, localizations made in the Pursuit condition of Experiment 1 were further in the direction of stimulus motion than those made in the Fixation condition, and the magnitude of this difference increased with increases in target velocity. Both results replicate a recent finding of Kerzel et *al.* (in press), save for the use of circular stimulus trajectories.

In the subsequent experiments, eye movements were suppressed, and observers' action plans did not require continuous anticipation of future positions of the moving target. Rather, the intended effect was the offset of the target, and it was accomplished via a button press. In this situation, we also expected localizations to be attracted toward the intended action effect. That is, localizations were expected to be biased toward the anticipated offset location. Indeed, in Experiment 2 localizations made in the Intention condition were further in the direction of the actual stopping position of the target (i.e. the location of the intended action effect) than those made in the Induction condition, even though (1) the action specified in the Intention condition involved a button press (i.e. not an eye movement), and (2) the action was not directed toward the moving stimulus. In the Induction condition, displacement varied with velocity in the same manner as Experiment 1. These findings indicate that at least a portion of the transformation of perceptual space associated with action control is due to action planning itself, and not to the specific effector specified in the action plan.

Experiment 3 was a replication of Experiment 2, save for a Cue condition in which participants were instructed to press a button in response to the onset of the moving stimulus. This experiment was devised to test whether differences in localization discovered in Experiment 2 were simply due to the fact that participants pressed a button in the Intention condition. If so, there should have been no differences between the Cue and Intention conditions. If, however, localizations made in Experiment 2 were due to action planning, then localizations made in the Intention condition should have been closer to the (intended) offset position than those made in the Cue condition. This is because, in the Intention condition, the final position of the moving stimulus was relevant to the action plan (i.e. press the button to stop the stimulus) while in the Cue condition, the initial position was relevant (i.e. press the button in response to the onset of the stimulus). In fact, Experiment 3 revealed that the differences in localization observed in Experiment 2 were due to action planning, not action execution.

Finally, in Experiment 4 we realized three versions of the Intention condition, each of which was programmed to produce a small degree of delay between the participant's button press and the actual offset of the moving stimulus. Our hypotheses were as follows: if the target moves beyond the intended stopping position, and participants have a tendency to localize the target toward the intended stopping position, localization scores should decrease with increasing delay between

button press and target offset (compared to the zero delay condition) as a larger distance between the intended stopping position and the actual stopping position is traversed. This hypothesis was confirmed. Of course, if action planning serves to bind perceptual space, then it should also lose its binding impact some time after the planned action has been executed. However, the 54 and 107 ms delays introduced in Experiment 4 were probably too short to unbind stimuli from action planning—a conclusion consistent with the observation that none of the subjects noticed the delays at all.

The present findings are consistent with the notion that action planning affects spatial localization. The action plans generated in all the experiments transformed perceptual space in an *intention-relative* fashion. Given this anticipatory, action-relative aspect of spatial localization, it seems difficult to sustain the representational momentum account and its assertion that localization error is due to action-independent post-perceptual cognitive momentum. In Experiments 1, 2, and 3, the error either disappeared or reversed (i.e. became negative) when observers were asked to generate action plans that did not involve (i.e. were not related to) the final position of the moving stimulus (i.e. the Fixation, Induction, and Cue conditions, respectively). This pattern of findings indicates that the error comes and goes as a function of an observer's intentional stance relative to the stimulus. If the intention is to stop a moving stimulus, there is no localization error because localizations are attracted toward the intended offset location. If the intention is to track a stimulus, there is localization error because continuous tracking requires continuous anticipation of future locations of the stimulus, and these anticipated locations are bound in the action plan because the intended distal effect is to stay on target. In short, localization error is not just related to action planning, it is dependent on it. Localization error, therefore, does not seem to be a property of post-perceptual cognitive processes. It seems, rather to be a property of the type of relationship one is attempting to maintain with a stimulus.

Given the present data and their support of the idea that localization error is dependent upon action planning, it seems difficult to sustain the functionally orthogonal, input–output approach to perception and action control that lies at the theoretical core of the representational momentum account. If perceptual processes and action-planning processes do share common mediation, the two, by definition, are dependent and, therefore, cannot be realistically modeled as constituting input- and output-control processes that are processed independently. Such problems do not arise in the Common Coding account, for the account asserts that action plans specify *distal effects*, not behavioral outputs. In addition, these distal effect plans are assumed to be processed via resources that are also used to perceive distal effects. As a result, spatial perception and action-control are not modeled as being functionally orthogonal. They are not assumed to be processed independently on opposite sides of the system. Instead, one might model them as being synergistically coupled. According to this approach (cf. also Jordan 1998, 1999), spatial perception and action planning, due to their common mediation, constitute a *distal-effect system* that allows one to both specify and detect distal events. This *distal-effect system*, however, although it is involved in action planning, is not responsible for the *effector control* required of an action. Its role, rather, is to constrain effector control systems toward the attainment of a specified distal effect. This implies it should be possible for action planning to produce transformations of perceptual space, regardless of the effector specified in the plan. This is exactly what happened in the present experiments. The action plans specified in Experiments 1 and 2 produced intention-relative shifts in spatial perception despite the fact Experiment 1 required eye movemets while Experiment 2 required finger movements.

Given this de-coupling of the systems underlying action planning and the systems underlying effector control, one can see how spatial perception and action control are synergistically coupled. As one

engages in effector control, one produces changes in body–environment relationships, and these changes feed back into the distal-effect system. This perceptual feedback then allows the distal-effect system to assess whether or not the specified distal effect (i.e. the action plan) has been attained. By being able to both specify the distal states toward which effector control systems are constrained, as well as detect the changes in distal states produced by effector control, the distal-effect system can be said to constitute a distal-effect control system. And as a result of the simultaneous mutual influence of effector control systems and distal-effect control systems, the two can be said to be synergistically coupled.

Given this approach, spatial perception and action control are not coupled in an orthogonal input–output fashion. Rather, they are nested control systems that are coupled synergistically. Action planning affects spatial localization therefore, because action planning and spatial perception share common mediation and, as a result, constitute aspects of the same distal-effect control system. This system, however, does not control distal effects by engaging in effector control. Rather, it does so by specifying the distal effects toward which effector control should be constrained, while simultaneously being sensitive to the changes in body–environment relationship produced by effector control.

In conclusion, this notion of synergistically coupled nested control systems may explain why it is possible to de-couple (dissociate) perceptual space and behavioral space (Bridgeman 1999, this volume. Chapter 5; Hansen and Skavenski 1985; Proffitt, Bhalla, Gossweiler, and Midgett 1995; Rossetti and Pisella, this volume, Chapter 4) but not perceptual space and action-planning space (Haggard, Aschersleben, Gehrke, and Prinz, this volume, Chapter 13; Hershberger and Jordan 1992; Jordan 1999; Rieser and Pick, this volume, Chapter 8; Viviani, this volume, Chapter 21). In the former. the two versions of space belong to functionally distinct, yet synergistically yoked control systems, while in the latter, they belong to the same system.

Acknowledgements

Note

1. If the description contains the degree scale only, the unit refers to the corresponding angle in respect to the circle! If scales giving both degree and millimeter are used, the units refer to the corresponding angle in respect to the eye.

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