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Thinking with portals: Revisiting kinematic cues to intention

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ABSTRACT

What we intend to achieve with our actions affects the way we move our body. This has been repeatedly shown for both, movement-related intentions such as grasping and turning an object, and relatively high-level intentions such as the intention to collaborate or to compete with a social partner. The impact of an intermediate level of intentions – referring to action-contingent changes in the physical environment – is far less clear, however. We present three experiments that aim at scrutinizing this level of analysis by showing how such anticipated consequences affect movement trajectories. Participants steered a virtual avatar toward portals that displaced the avatar to a different but predictable location. Even though this displacement occurred only after the movement was completed, hand movements were clearly torn toward the anticipated final location of the avatar. These results show that properties of anticipated action consequences leave a fingerprint on movement trajectories and provide an opportunity to unite previous accounts on the relation of intentions and movements with general frameworks of action planning.

1. Introduction

1.1. Intention, goals, action

A person can carry out identical motor actions with different intentions in mind. For example, a window may be opened to air the room, to call for someone outside, or even to climb through it. One may argue that without knowing the actor's intention, it would be impossible to say whether a given motor action served one purpose or another.

Experimental evidence, however, suggested this argument to be incorrect. In fact, motor actions that appear superficially similar can differ in subtle respects, and observers may use that information to infer an actor's intentions. For instance, Georgiou and colleagues asked their participants to reach toward an object, a wooden block, and to place it at a specific location on a table (Georgiou, Becchio, Glover, & Castiello, 2007). Participants were tested in pairs and performed either in a cooperative task, in which they were to place the blocks next to each other, or in a competitive task, in which each participant tried to place their own block faster than the competitor (see Becchio, Sartori, Bulgheroni, & Castiello, 2008b, for a similar design). Kinematic parameters of these conditions were compared to control conditions in which participants performed either natural or fast placement actions (with natural actions being the control condition for cooperation and fast actions being the control condition for competition). The resulting kinematic parameters of cooperative and competitive movements differed from those in the respective control conditions, indicating that the social goals of these actions did affect motor control. In light of such findings, it does indeed seem as if merely observing actions could provide the observer with cues about the actor's goals and, ultimately, his intentions (Becchio,

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Manera, Sartori, Cavallo, & Castiello, 2012; Blakemore & Decety, 2001; Sartori, Becchio, & Castiello, 2011).

Whether or not this conclusion is appropriate, however, depends on the nature of the intentions one talks about (Jacob & Jeannerod, 2005; Pacherie, 2000). Obviously, action goals can differ regarding their levels of proximity and abstractness and likewise many authors, from such diverse fields as philosophy of mind to neuroscientific approaches, have distinguished several types of intentions according to their temporal distance from a particular movement. For example, Pacherie (2008) distinguishes distal, proximal, and motor intentions, Bratman (1987) distinguishes future- and present-directed intentions, and Haggard (2008) compares long- and short-range intentions. A very general difference is illustrated with Searle's (1980, 1983) distinction of *intentions in action* and *prior intentions*. Considering the aforementioned study by Georgiou et al. (2007), the intention to behave cooperatively or competitively would be an instance of a prior intention. Critically, no movement will be emitted by this prior intention alone; rather one also needs to form an additional intention in action to make this happen. As such, intentions in action are intimately linked to the particular movement they cause, and guide rather specific aspects of an action. Prior intentions, by contrast, are less specific and represent the action as a whole, including the intention in action and the intention in action's causing the corresponding movement.

This analysis suggests that previous research mostly aimed at documenting how movements are affected by prior intentions, such as the intention to collaborate as compared to compete (Becchio et al., 2012), or to communicate with another agent (Sartori, Becchio, Bara, & Castiello, 2009, cf. also Becchio, Sartori, Bulgheroni, & Castiello, 2008a; Becchio et al., 2008b; Georgiou et al., 2007; Ray & Welsh, 2011). Even though others raised philosophical objections against the very possibility of such influences (Jacob & Jeannerod, 2005), there seems to be tacit agreement that at least intentions in action can be readily captured by observing the corresponding movements (see also Ansuini, Giosa, Turella, Altoè, & Castiello, 2008; Herbort, Koning, van Uem, & Meulenbroek, 2012). But is this latter, cautious conclusion actually backed up by the available evidence? We suggest that this is only partly the case and that a central content of intentions in action has not been scrutinized so far. More precisely, even with intentions in action, there is a separation between the motor act itself and possible changes in the physical environment that this action aims at. Consider again, Searle (1983, p. 133) to illustrate this point[1]:

> "Suppose as I raise my arm I discover to my amazement that the window across the room is going up. And suppose as I lower my arm the window goes down. In such a case I will wonder if my raising and lowering my arm is making the window go up and down. In order to find out I will try again. Suppose it works a second time. My Intentional content will be altered on subsequent occasions. I am no longer just raising my arm; but I am *trying to* raise and lower the window [...]".
>
> [italics in the original]

In other words, considering the instrumental character of a motor action, e.g., aiming at producing certain movements of a window, adds new content to the intention in action's conditions of satisfaction. In the present paper we ask whether this additional intentional content, i.e., the intended physical action outcome, also shapes motor execution. To stick to the window example, we investigated whether the experience that *raising* the arm makes the window go *down* rather than up changes the way the arm is moved. In fact, there are good reasons to expect such an influence. These expectations are motivated by a different theoretical perspective, ideomotor theory, which we describe in the following.

1.2. Ideomotor theory

Ideomotor theory offers a simple, yet powerful approach to human action control, whose philosophical roots have mainly been elaborated in the 19th century (Harleß, 1861; Herbart, 1825; James, 1890; for historical comments see Pfister & Janczyk, 2012; Stock & Stock, 2004). The theory's central assumption is that agents acquire *bidirectional* associations between own body movements and following perceivable changes, i.e., action effects. The attribute 'bidirectional' hereby indicates that these associations not only allow predicting the possible effects of an action but also that they enable representations of potential action effects to activate the associated action (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Shin, Proctor, & Capaldi, 2010). Due to this architecture, motor control is possible by anticipating intended action effects, which in turn activates the corresponding movements (Kunde, 2001).

This short description already seems to share some central features with Searle's (1983) theory of intentionality in general, and particularly with the above-sketched notion of intentional causation of effects in the environment. The example of the window going up or down as a function of the agent's arm movements, for instance, can be viewed as an environment-related action effect in the ideomotor framework. The intention to raise or lower the window, in Searle's terms, would thus correspond to addressing the arm movement (partly) via anticipations of the intended changes of the window position. Due to this similarity, ideomotor effect anticipations, in fact, have been suggested as a candidate mechanism to explain how intentions in action ultimately cause body movements (Stock, 2004; for a related discussion of psychological equivalents to intentions in action, see Pacherie, 2000). The question of whether or not movement kinematics are influenced by the intention in action's content relating to the external world, can thus be tackled with the methodological tools for studying ideomotor effect anticipations.

A useful approach to studying such anticipations is the response–effect (R–E) compatibility paradigm (Kunde,

[1] This example is motivated by Stock (2004) who quoted the corresponding paragraph of the German translation (Searle, 1996) to argue that prior intentions and intentions in action also comprise perceivable effects of an action with regard to predictable changes in the agent's environment.

2001). In this paradigm, responses are coupled with certain effects in a way that responses and effects vary on a common dimension. This dimensional overlap allows for creating compatible and incompatible conditions (Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990). For instance, "left" responses would trigger action effects to the left of the participant in a compatible condition whereas they would trigger action effects to the right of the participant in an incompatible condition. Such action effects obviously may relate to proprioceptive and tactile consequences such as vibrations occurring at one or the other limb (Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014), or they may be any other kind of sensory action effect (e.g., Ansorge, 2002; Chen & Proctor, 2013; Janczyk, Pfister, Crognale, & Kunde, 2012; Kunde, 2001, 2003; Kunde, Lozo, & Neumann, 2011; Kunde, Müsseler, & Heuer, 2007; Pfister, Dignath, Hommel, & Kunde, 2013; Pfister & Kunde, 2013; Yamaguchi & Proctor, 2011). As a reliable finding across these studies, responses are initiated faster when responses and their to-be-produced effects are compatible rather than incompatible. Because the effects only occur after action initiation, these findings clearly indicate that effect *anticipations* are at work during action selection and planning (see also Janczyk, Pfister, Hommel, & Kunde, 2014, and Janczyk, Skirde, Weigelt, & Kunde, 2009; for converging results from other paradigms).

Whether or not such anticipations also affect the trajectories of a manual movement has not been studied to date, though. We thus examined movement trajectories in a speeded classification task – navigating an avatar toward a virtual cake – while dissociating the final movement location from the effect location in an R–E compatibility design. To anticipate the results, trajectories were indeed attracted to the position of the anticipated action effect if its location conflicted with the endpoint of the required response. Our results indicate that intended action effects as part of an intention in action have the power to shape movements up the point of movement completion.

2. Experiment 1: Thinking with portals

To measure the impact of anticipated action effects – i.e., those aspects of an intention in action going beyond the bodily movement – on movement planning and execution, we used an R–E compatibility paradigm (Kunde, 2001) in which participants operated a computer mouse to control a virtual avatar. In each trial, the avatar had to move to a target at the top-left or top-right of the computer screen to receive a complimentary cake. Each of the targets resembled a portal and made the avatar appear at one of two final locations. This location was either spatially compatible or spatially incompatible to the movement's endpoint (see Fig. 1). More precisely, compatibility of the movement's endpoint and the final effect location varied from trial to trial (cf. Gaschler & Nattkemper, 2012; Pfister, Kiesel, & Melcher, 2010), but was predictable by the appearance of the portals: A portal that was designated to be switched off made the avatar appear at a compatible location (Fig. 1a), whereas the avatar appeared at an incompatible location if the portal was designated to be switched on (Fig. 1b).

An analysis of the movement trajectories allowed us to pinpoint influences of the compatibility between the movement direction and the direction of its merely anticipatable effect. More specifically, we hypothesized movement trajectories to be attracted toward the final location in case of incompatible trials. Such a deflection should be evident in two measures: The maximum absolute distance (MAD) between the actual trajectory and a straight line from start- to end-point, and the corresponding area under the curve (AUC). These measures were complemented by two additional variables: The time it took to initiate a movement (initiation time; IT) and the following movement time (MT).

2.1. Methods

2.1.1. Participants

We recruited twenty participants (mean age = 20.8 years, 15 female, 3 left-handed). Handedness was determined via self-report and all participants further reported normal vision and hearing. They were naïve concerning the hypotheses of the experiment.

2.1.2. Apparatus and stimuli

Stimuli appeared on a 17″ monitor and were adapted from the computer game *Portal* (www.thinkwithportals.com; see Fig. 1). The screen was divided by two walls (height: 1.7 cm), appearing at a distance of 4.5 cm from wall midline to upper and lower screen border, respectively, resulting in a distance of 15 cm between the walls. The bottom wall had a door (2.5 cm × 2.2 cm) in its center whereas the top wall had two doors, appearing 8.5 cm from the left or right screen border, respectively. The door in the bottom wall served as the start position whereas the two doors in the top wall contained a virtual cake that participants were told to collect in each trial. These cakes differed in color (yellow vs. red) and the assignment of cake color to door position was constant for each participant (counterbalanced across participants).

Two portals (1.3 cm × 2.2 cm) were placed 3.5 cm below each door of the top wall. These portals were either switched off (indicated by an "X" on red ground) or switched on (indicated by a check mark on green ground). The distance between start position and each of the portals was approximately 14 cm. Imperative stimuli appeared in the center of the top wall (1.9 cm × 2.7 cm) and consisted of the written instructions "Gelber Kuchen!" (German for "Yellow cake!") or "Roter Kuchen!" ("Red cake!"). They were supplemented by a female voice giving the corresponding instructions verbally via loudspeakers. Participants operated a standard computer mouse and the mouse cursor was substituted for a schematic avatar (0.7 cm × 1.5 cm).

2.1.3. Instructions

At the beginning of the session, participants were familiarized with the stimulus setup, starting with a stimulus display that only consisted of the two walls, the corresponding (closed) doors, and the avatar who spawned

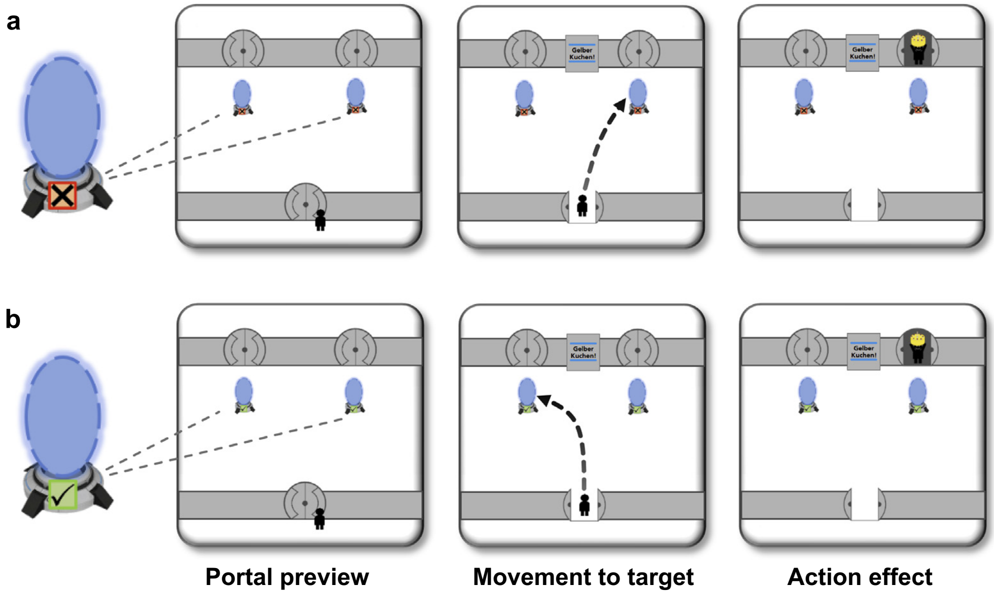

Fig. 1. Trial procedure of Experiment 1 for (a) compatible trials (portals off) and (b) incompatible trials (portals on). To start a trial, participants approached the door in the bottom center of the display; this initial task also ensured that participants had ample time to encode the portal status (indicating the current compatibility relation). After a dwell time of 500 ms, the door opened and the imperative stimulus ("Red cake!" vs. "Yellow cake!") was displayed in the top center of the screen, supplemented by the corresponding verbal instruction via loudspeakers. The assignment of cake colors to doors (left vs. right) was constant for each participant, so that the correct movement was a direct function of the instructed cake color and the current portal status (compatibility relation). Entering the correct portal was followed by an action effect (the avatar holding the cake) whereas entering the wrong portal made a sad avatar appear in the corresponding door.

below the bottom wall. To pass this wall, participants had to place the avatar in front of the door which opened after a dwell time of 500 ms. They were then instructed to explore the function of the top doors which opened instantly when the avatar stood in front of them and closed as soon as the avatar was moved away. Each door contained either a yellow or a red cake and the participants were told to remember the cake positions. After this initial familiarization, the experimenter introduced the concept of portals and explained that, upon entering, the avatar would be teleported to one of the doors. If portals were switched on, they would relocate the avatar to the door at the other end of the hall whereas a portal that was designated to be switched off would not affect the avatars left/right position but rather teleport the avatar to the spatially corresponding door. Participants were given time to explore the relation of portal status (on or off) to which door was reached upon entering one of the portals.

2.1.4. Procedure

Participants completed one practice block and four experimental blocks of 56 trials each. The trial number resulted from 14 repetitions of each combination of two possible end directions (left vs. right; i.e., yellow vs. red cake) and two possible compatibility relations (compatible vs. incompatible; i.e., portals off vs. portals on). Each block was followed by short break in which participants were informed about their average time to complete a trial and the number of errors.

The trial procedure is illustrated in Fig. 1. At the beginning of a trial, the avatar spawned below the bottom wall and participants were given time to check whether the portals were switched on or off. To continue, the participants moved the avatar in front of the central door which opened after a dwell time of 500 ms. Then the imperative stimulus was displayed and simultaneously presented via loudspeakers. From this point onward, the cursor position was recorded until the end of the trial (effective sampling rates were between 50 and 100 Hz, depending on current CPU load).

Participants were instructed to move as quickly as possible to the portal that would teleport the avatar to the correct location. Furthermore, they were told not to touch the bottom wall which instantly aborted the trial, followed by an error message. Upon reaching a portal, the avatar was teleported to the corresponding door. In case of correct responses, the avatar was displayed with a happy face and holding the attained cake, whereas the avatar was displayed with a sad face if the participant had aimed for the wrong location. This feedback stayed on screen for 2000 ms and mouse movements did no longer affect the display. Finally, the screen was cleared and the next trial started after 1000 ms.

2.1.5. Data treatment

Initiation time (IT) was measured as the time from the onset of the imperative stimulus until the cursor's y coordinate first exceeded the coordinates of the borders of the bottom wall, and MT was measured from this point until the cursor hit the borders of a portal. Trajectory data for the following movement to one of the portals was analyzed via custom MATLAB scripts. Cursor x and y coordinates were first transformed to a coordinate system with origin at the starting position. Movements to the left were mirrored at the vertical axis to allow for aggregation across both movement directions. Then, cursor coordinates were time-normalized to 101 steps via linear interpolation.

The interpolated data was used to extract MAD and AUC from the trajectories of each individual trial. MADs were computed as the (signed) maximum distance between actual and optimal trajectory (with optimal trajectory being defined as a straight line from start to end coordinates). MADs were coded with a positive sign if the maximum deviation aimed toward the side of the opposite portal and with a negative sign if the maximum deviation aimed away from the opposite portal. Similarly, AUCs were computed as the discrete integral between actual and optimal trajectory, with deviations toward the opposite portal counting as positive values and deviations away from the opposite portal counting as negative.

2.2. Results and discussion

Prior to analyzing the four variables of interest (IT, MT, MAD, and AUC), we excluded trials in which the avatar collided with the top or bottom wall (7.3%). Similarly, we excluded trials in which participants moved to the wrong portal (1.8%), what happened more often in incompatible trials (portals on; 2.3%) than in compatible trials (portals off; 1.3%), $t(19) = 2.05$, $p = .055$, $d = 0.46$. Furthermore, the remaining trials were subjected to an outlier correction with outliers being defined as any measure deviating more than 2.5 standard deviations from the corresponding cell mean, computed separately for each participant and compatibility condition (7.2%).

As shown in the top-left panel of Fig. 2, movement trajectories were indeed slightly more biased toward the opposite goal location in the incompatible condition (portals on), as compared to the compatible condition (portals off). This difference occurred very systematically, giving rise to a significant difference for both, MAD (72 px vs. 64 px), $t(19) = 3.36$, $p = .003$, $d = 0.75$, and AUC (18,281 px^2 vs. 16,184 px^2), $t(19) = 3.77$, $p = .001$, $d = 0.84$ (see also Fig. 3). Moreover, ITs were descriptively longer in the incompatible condition than in the compatible condition (626 ms vs. 611 ms), $t(19) = 1.96$, $p = .064$, $d = 0.44$, and a significant difference in the same direction was present for MTs (634 ms vs. 580 ms), $t(19) = 3.39$, $p = .003$, $d = 0.76$.

An additional analysis targeted the time-course of the observed effects across the movement trajectory. To this end, we compared the *mean* absolute distance for each normalized time-slice between incompatible and compatible trials (Fig. 2, lower left panel). This analysis showed differences in trajectory deflection to peak at 70% of the movement, with a mean absolute distance of 8 px, $t(19) = 3.79$, $p = .001$, $d = 0.85$.

The results of Experiment 1 confirm the hypothesized influence of anticipated action effects in the agent's environment on movement trajectories. Experiment 2 therefore aimed at replicating the observed effects in a situation that places less constraints on possible movement trajectories of the participants.

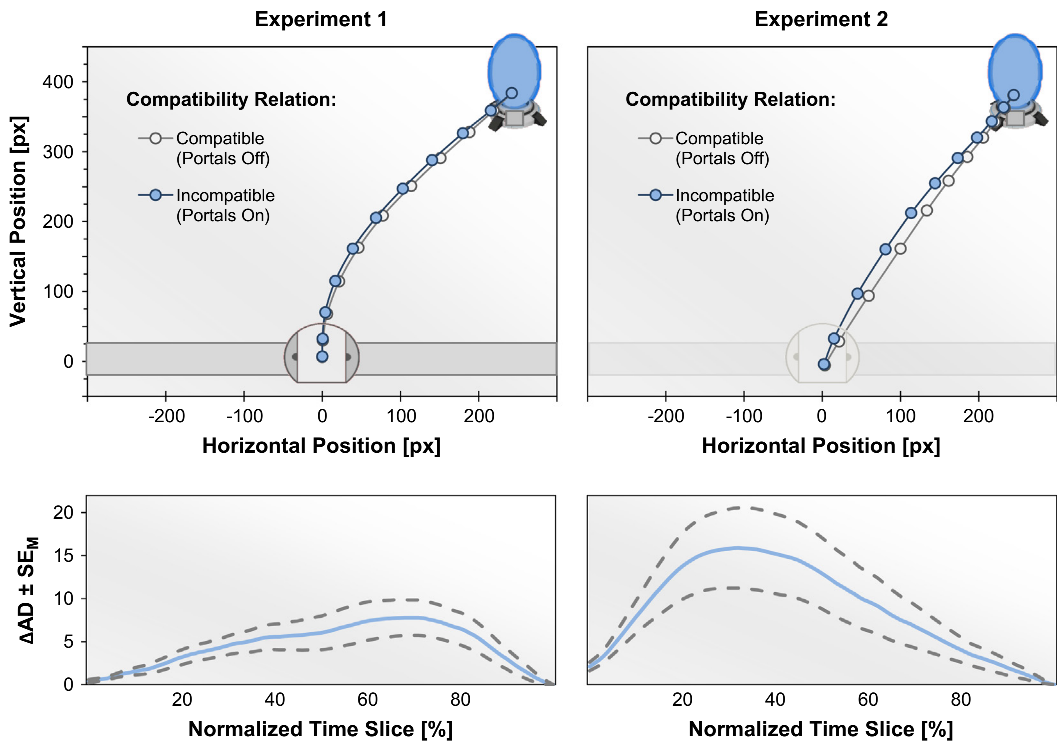

Fig. 2. Trajectory data of Experiments 1 and 2. If a movement was going to result in a spatially incompatible relocation of the avatar, movement trajectories were biased toward the anticipated final location. Reliable differences at the very beginning of the movement interval are driven by different starting angles when passing the boundaries of the bottom wall.

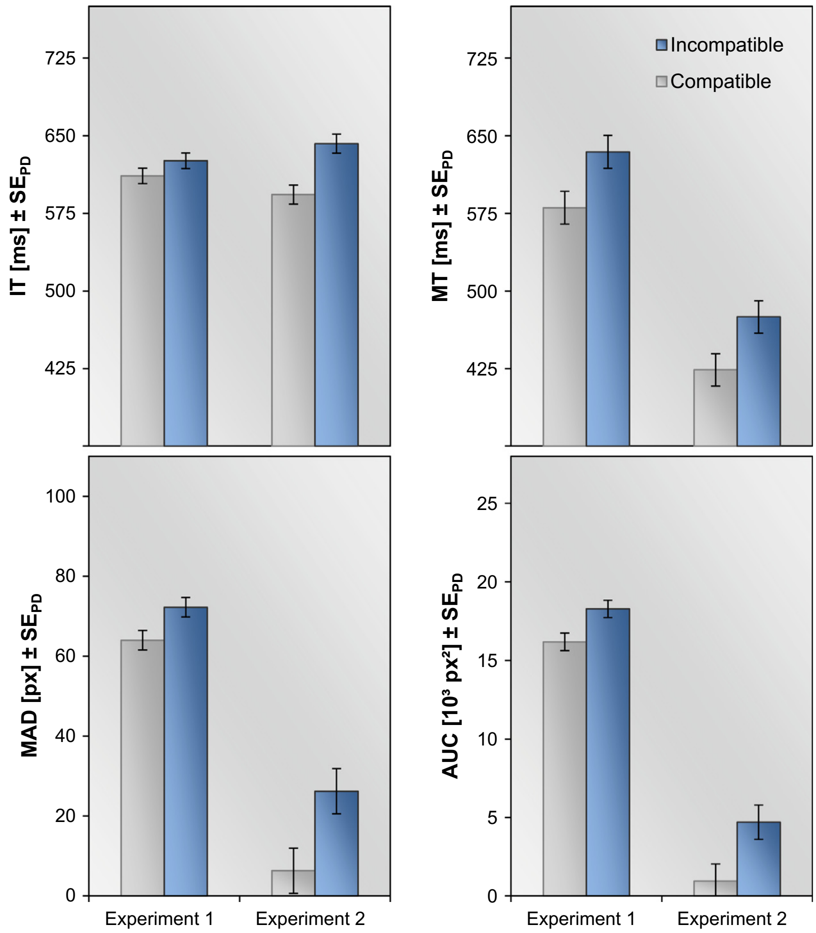

Fig. 3. Descriptive statistics for the four variables of interest in Experiments 1 and 2. Error-bars represent standard errors of paired differences (Pfister & Janczyk, 2013), computed separately for each experiment.

3. Experiment 2: Unconstrained movements

An objection against the results of Experiment 1 can be derived from the design as depicted in Fig. 1: Because participants were forced to pass through the bottom wall in vertical direction when starting their movements, they were not able to head directly to the portal but rather had to start more or less in parallel to the vertical midline of the display. Accordingly, the movements were already biased away from their target location in the first place which might have rendered the trajectories particularly sensitive to our experimental manipulation. We therefore replicated the overall design but had the bottom wall disappear as soon as participants were allowed to start their movement.

3.1. Methods

3.1.1. Participants

We recruited a new sample of twenty participants (mean age = 21.5 years, 14 female, 1 left-handed, 1 ambidextrous). All participants reported normal vision and hearing and were naïve concerning the hypotheses of the experiment.

3.1.2. Apparatus, stimuli, and procedure

The setup was identical to Experiment 1, with the only exception that the bottom wall and the corresponding door disappeared as soon as the dwell time had elapsed. Participants were thus no longer confined in their movements and collisions could only occur with the top wall.

3.2. Results and discussion

Not surprisingly, fewer collision errors occurred than in Experiment 1 (1.7%), whereas movements to the wrong portal (2.3%) occurred again more often in incompatible than in compatible trials (3.3% vs. 1.3%), $t(19) = 4.77$, $p < .001$, $d = 1.07$. Outliers were removed according to the same criteria as for Experiment 1 (6.3%).

Overall, the trajectory data consistently replicated the findings of Experiment 1 with even stronger numerical effects (Fig. 2, top-right panel). Accordingly, we again observed a significant compatibility effect for both, MAD (26 px vs. 6 px), $t(19) = 3.52$, $p = .002$, $d = 0.79$, and AUC (4,703 px^2 vs. 952 px^2), $t(19) = 3.40$, $p = .003$, $d = 0.76$ (see also Fig. 3). Furthermore, ITs were longer in the incompatible condition than in the compatible condition (642 ms vs.

593 ms), $t(19) = 5.32$, $p < .001$, $d = 1.19$, and so were the corresponding MTs (475 ms vs. 424 ms), $t(19) = 3.27$, $p = .004$, $d = 0.73$. The additional time-course analysis showed the mean absolute distance to peak considerably earlier than in Experiment 1, at 32% of the movement (Fig. 2, lower left panel; mean distance = 16 px), $t(19) = 3.40$, $p = .003$, $d = 0.76$.

In a nutshell, Experiment 2 replicated the critical findings of Experiment 1 by showing an impact of anticipated action effects on movement trajectories. Before drawing any conclusions from these findings, however, the following Experiment 3 rules out a final objection against the validity of our approach.

4. Experiment 3: Memory confounds?

The preceding experiments documented a profound impact of anticipated action effects on movement trajectories. Yet, it is not clear whether the anticipated effects were actually used for motor control or whether the mere imagination (Tlauka & McKenna, 1998) or knowledge of upcoming sensory events influenced trajectories, e.g., via deployment of attention to the final location. Even though simply maintaining a representation of upcoming sensory stimuli tends to draw movements away from these locations instead of toward them (Belopolsky & Theeuwes, 2009; Theeuwes, Olivers, & Chizk, 2005; Tipper, Howard, & Jackson, 1997; Walker, McSorley, & Haggard, 2006), this issue clearly called for empirical clarification (for the possibility of anticipated but merely imagined action effects influencing action control, see Pfister, Pfeuffer, & Kunde, 2014).

We therefore changed a critical aspect of the task of Experiment 1 to rule out this alternative explanation. Participants did no longer receive a virtual cake after having arrived at a portal, but instead, the imperative stimulus now specified directly whether to move to the left or right portal. Before the movement, however, participants were shown a red or yellow cake in the left or right door (manipulated orthogonally to the required movement direction). They had to keep this item in memory throughout the movement and were probed for it at the end of the trial. Participants therefore had to maintain a representation of this object in memory just as in Experiments 1 and 2, and the factor compatibility now related to the match between the location of the memory item (left vs. right door) and the required target direction (left vs. right portal). Importantly, the representation was no longer relevant for motor control; we therefore expected a reduced or possibly absent effect of compatibility in this experiment.

4.1. Methods

4.1.1. Participants

We recruited a new sample of twenty participants (mean age = 23.5 years, 16 female, 2 left-handed). All participants reported normal vision and hearing and were naïve concerning the hypotheses of the experiment.

4.1.2. Apparatus, stimuli, and procedure

The general setup was similar to Experiment 1, with one critical modification. After participants had spent the dwell time at the bottom door, a memory item (red or yellow cake) appeared in the left or right door for 750 ms (without being backed up by voice recordings). Participants had to memorize identity and location of this memory item for the remainder of the trial. Then, the imperative stimulus set on (750 ms): The letter L or R appeared in the top-center of the screen and called for a movement to the left or right portal. Direction of the movement and location of the memory item were manipulated orthogonally.

Upon arrival at the portal, the avatar disappeared. After 500 ms, a cake probe appeared in one of the portals. Each block of 56 trials featured 32 trials in which memory and probe matched, 8 in which the cake appeared in the wrong door but in the correct color, 8 in which the cake appeared in the correct door but in the wrong color, and 8 in which the wrong cake appeared in the wrong door. In all cases, the probe was accompanied by the question: “Is this the correct cake at the correct location?”. Participants responded at leisure by pressing either the left (“yes”) or right (“no”) mouse button. Correct answers showed a happy avatar holding the original cake in the correct door, whereas wrong answers showed a sad avatar without cake.

4.2. Results and discussion

Overall, participants performed the memory task very accurately, with only 2.8% memory errors. Collisions with the wall happened in 4.0% of the trials, and response anticipations (movement initiation before target onset, probe response before question onset) occurred in another 3.3%. Movements to the wrong portal were very rare (0.2%) and occurred only in the incompatible condition. Not surprisingly, a comparison of movement errors between the compatible and the incompatible condition was significant, $t(19) = 3.20$, $p = .005$, $d = 0.72$. Outliers were removed according to the same criteria as for Experiment 1 (6.5%).

In short, we did not observe any reliable effects of compatibility on any of the variables of interest. Descriptively, ITs were longer in the incompatible condition than in the compatible condition (700 ms vs. 693 ms), $t(19) = 0.84$, $p = .409$, $d = 0.19$, and so were MTs (714 ms vs. 703 ms), $t(19) = 1.34$, $p = .197$, $d = 0.30$, but these effects did not approach significance. MADs were slightly lower in the incompatible condition (67 vs. 68 px), but this small difference was in the opposite direction as for the preceding experiments and failed to reach significance, $t(19) = -1.31$, $p = .098$, $d = -0.39$. The same was true for AUC (17,377 px^2 vs. 17,712 px^2), $t(19) = -1.37$, $p = .187$, $d = -0.31$.

More important than the absence of effects for Experiment 3, however, is a direct comparison of Experiments 1 and 3. Accordingly, we re-analyzed each dependent variable with separate 2×2 split-plot analyses of variance (ANOVAs) with compatibility (compatible vs. incompatible) as repeated measure, and experiment

(1 vs. 3) as between-subjects factor. For IT, this analysis did not yield a significant interaction, $F(1,38) = 0.49$, $p = .487$, $\eta^2_p = .01$, whereas the interaction was significant for the remaining three variables; MT: $F(1,38) = 5.81$, $p = .021$, $\eta^2_p = .13$; MAD: $F(1,38) = 13.87$, $p < .001$, $\eta^2_p = .27$; AUC: $F(1,38) = 16.02$, $p < .001$, $\eta^2_p = .30$. The main effect of experiment was not significant for any of these ANOVAs ($ps > .149$, $\eta^2_p < .06$). These findings indicate that the results of Experiments 1 and 2 are indeed driven by active anticipations rather than passive knowledge of certain stimulus locations (Theeuwes et al., 2005; Tlauka & McKenna, 1998; Walker et al., 2006).

5. General discussion

The present study demonstrated an impact of anticipated action effects in the agent's physical environment on movement trajectories. When actions were to produce an effect at an incompatible location, e.g., the avatar appearing in the right door following a leftward movement, the trajectory of this movement was attracted toward the effect location (Experiments 1 and 2). Furthermore, Experiment 3 ruled out an alternative explanation in terms of the mere knowledge about the position of certain stimuli that might have influenced the attentional focus of the participants. Applied to Searle's (1993) example of raising and lowering the arm to control a window: It does indeed seem as if we raise our arm somewhat differently when raising the arm will cause the window to move down rather than up.

These results extend previous studies on the effect of social intentions on movement planning (Becchio et al., 2012; Georgiou et al., 2007; Sartori et al., 2009), by showing that predictable changes in the agent's physical environment shape movement trajectories in a systematic manner. It should also be noted that this influence occurred even though the task did not specifically encourage participants to plan their movement trajectories with regard to the anticipated action effects. Such planning ahead is obviously relevant for most transitive actions that were studied in the context of intentions in action (Ansuini, Santello, Massaccesi, & Castiello, 2006; Ansuini et al., 2008). More precisely, actions such as lifting, throwing, or rotating a physical object, imply action sequences that can only be performed efficiently if early aspects of these actions are planned with respect to upcoming task demands and biomechanical constraints (Cohen & Rosenbaum, 2004; Herbort & Butz, 2012; Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; Rosenbaum et al., 1990; Weigelt, Kunde, & Prinz, 2006). Accordingly, these tasks imply that intentions such as throwing or turning an object are already reflected in early phases of the movement kinematics and can be inferred by an observer (Herbort et al., 2012). In the task of the present experiments, by contrast, compatibility of the mouse movement direction and the ensuing action effect did not necessarily have to be taken into account during movement planning, because the relocation of the avatar did not require any additional movements of the participants.[2]

The present experiments are thus a clear-cut demonstration of how sensory anticipations affect movement trajectories even if this impact does not depend on motor-related constraints of the actions in question. It is also important to note that the movements in the present design were instrumental, i.e., they aimed at receiving a cake at the end of the trial. Our results therefore complement previous research on the intentional induction of incidental movements that were similarly inspired by the framework of ideomotor theory (Knuf, Aschersleben, & Prinz, 2001). In these experiments, participants watched a billiard ball missing its target in some trials after having experienced control over either the ball movement or the target position in early phases of a trial. Even though participants were aware that after this early phase they would not be able to control the ensuing events anymore, they still showed covert movements to correct the erroneous trajectory. Thus, the mere intention to hit a given target led to subtle but predictable control movements even though these movements were clearly ineffective (see also De Maeght & Prinz, 2004; Häberle, Schütz-Bosbach, Laboissière, & Prinz, 2008; Prinz, De Maeght, & Knuf, 2004). The present results go beyond this influence by demonstrating a similar effect of instrumental movements that are performed with different intentions in mind.

The direction of the observed effects – attraction to the anticipated action effects – is also well in line with recent findings on the impact of conflicting stimuli on motor planning and execution (Buetti & Kerzel, 2008, 2009; Scherbaum, Dshemuchadse, Fischer, & Goschke, 2010; Welsh & Elliott, 2004, 2005; Welsh, Elliott, & Weeks, 1999). These studies showed mouse or arm movements to be affected by the presence of distracting stimuli in the environment, especially in terms of the task-irrelevant location of the target stimuli. These target stimuli obviously appeared prior to, or during movement execution; by contrast the action effects of the present study only occurred after movement execution so that our results are likely driven by anticipative rather than perceptual processes.

Arguably, the observed impact of anticipated actions effects may be explained by two distinct mechanisms: The location of the anticipated action effects might bias early phases of movement planning and possibly even the decision which specific movement to execute, or, alternatively, anticipated action effects might shape online movement execution by sustained activation of the anticipated action effect (Kunde, Koch, & Hoffmann, 2004; Shin & Proctor, 2012). These mechanisms are not mutually exclusive and both may drive the observed results. Given that reliable effects of R–E compatibility were already

[2] Even though the avatar was teleported automatically to its final location, this procedure is likely to have involved additional saccades toward the final location. Such eye movements were of course not required to complete the task, but pre-planning such a movement may partly be responsible for the observed effects. Further scrutinizing the role of saccadic eye movements for spatial R–E-compatibility effects certainly seems to be a promising field of inquiry (for comments on the role of action effects for oculomotor control, see Herwig & Horstmann, 2011, and Huestegge & Kreutzfeldt, 2012).

evident in very early phases of the movement (already when leaving the home area in case of Experiment 2), it seems likely that the present effects emerged at least partly during action planning. Further support for this notion comes from a recent study on the impact of anticipated action effects on saccadic eye movements (Herwig & Horstmann, 2011). In this study, participants were asked to make a saccade from the center of the computer screen to a face that was displayed to the left or right side. Before the saccade, the faces always showed a neutral expression that predictably changed to either happy or angry as soon as the saccade landed on it (i.e., fixating the face made its expression change instantly). Interestingly, the vertical landing positions of the saccades were centered on the mouth region for faces that would turn happy (focusing on the corresponding smile) whereas the vertical landing positions were centered on the eyebrows region for faces that would turn angry (focusing on the frown). These observations indicate that anticipated action effects might indeed affect the target location of a saccadic action and the same might hold true for the planning of manual actions. Of course, an early impact of anticipated action effects might still be supplemented by an influence of effect anticipations on online control processes during movement execution. Such a combined impact of action effects on planning as well as online control would be well in line with previous accounts for the impact of anticipated action effects on the execution of discrete keypress responses (Kiesel & Hoffmann, 2004; Kunde, 2003; Kunde et al., 2004), even though the present experiments were admittedly not designed to disentangle the relative contribution of both mechanisms (for additional discussions on movement planning vs. control, see Franz, Scharnowski, & Gegenfurtner, 2005, and Glover, 2004).

In any case, our results document a profound impact of anticipated events – as content of intentions in action in Searle's (1993) terminology – on movement trajectories. In turn, motor execution may also help to decipher hidden intentions in action, e.g., during human–computer interaction. Furthermore, the present setup also opens up an interesting possibility to be used in the reverse direction: Rather than manipulating intentional content (the location of a to-be-obtained cake) and measuring its impact on movement trajectories, it would similarly be possible to alter the trajectories that are displayed on screen and investigate the impact of this manipulation on the subjective intentional content. Such an impact of self-perception on intentions, affective states, and attitudes has a long tradition in psychological theorizing – from James (1884) to Bem (1967) –, and the present setup might serve as a powerful tool to study the microgenesis of such motivational–emotional states from observing one's own behavior.

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