Recall of Observed Actions Modulates the End-state Comfort Effect Just like Recall of One´s Own Actions

David Dignath and Andreas B. Eder

University of Würzburg, Germany

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Address information for David Dignath (corresponding author):

Department of Psychology, University of Würzburg

Röntgenring 10

97070 Würzburg, Germany

Tel: +499313185228

Fax: +49 931 31 82812

Email: david.dignath@psychologie.uni-wuerzburg.de

Abstract

Previous studies showed that initial comfort of a posture is traded for a better control at the end position, a phenomenon which has been termed the end-state comfort effect. When participants recall a recently performed motor plan, the end-state comfort effect is reduced. Two experiments investigated whether observing the grasp of another person is sufficient for later recall. Participants moved an object from a home location to different target positions. Results replicated an end state comfort effect, revealing an inverse relation of grasp height to target height for the first movement. When participants later returned the object back to the home position, recall of the previously self-performed action dominated, replicating the reduction of end-state comfort due to recall processes. Notably, the end-state comfort effect was also reduced in conditions in which a model performed the first movement and in which the participant performed only the second movement (Experiment 1). Model actions were also recalled in situations in which the observed action was incongruent with a comfortable end position of the participant (Experiment 2). These results suggest that observed actions of others can serve as templates for movement planning in social situations. (191 words)

Keywords: end-state comfort effect; motor planning; action observation; action simulation; imitation; hysteresis

The way people initiate a specific movement is determined by the goal they want to accomplish. Much research has shown that movement parameters depend on the anticipated end-state of an action (e.g. Rosenbaum, Marchak, Barnes, Vaughan, Slotta, & Jorgensen, 1990; for an overview see Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012). A goal dependency of movements is not only essential for planning one's own action but it also allows agents to infer the goals of other people via observation. For instance, in a social situation in which a person observes another person grasping a bottle, the observer will infer from specific kinematic cues that the other person intends to fill the glass (Becchio, Sartori, Bulgheroni & Castiello, 2008). Moreover, the capacity to infer the goals of others is especially important when people cooperate with other people. Observing that a bar keeper reaches a glass to a customer may motivate the customer to move the own arm in the direction of the bar keeper. For an account of social cooperation, theorists have proposed that understanding and prediction of others' actions involves a covert reenactment of the observed action (Gallese & Goldman, 2008; Jeannerod, 2006). This study investigated whether a covert reenactment of observed actions affects action planning of the observer by providing a template for how to perform an own movement.

Plan Generation and Action Recall in Anticipatory Movement Planning

Rosenbaum and colleagues (1990) observed in an intriguing study that participants grasp a bar according to the end position in which the bar should be placed. When turning the bar around from one end to the other, participants initially grasped the bar with an uncomfortable, thumb down grasp to achieve an end-position with a comfortable thumb up grasp. An end-state comfort effect was also observed with lifting movements in a vertical direction. In one study, participants moved a plunger from a home position to target positions at different heights. The height of the target location systematically influenced the initial grasp position: When the plunger was moved up, the initial grasp height was low; in contrast, initial grasp height was high, when the plunger was moved down (Cohen & Rosenbaum, 2004).

The end-state comfort effect suggests that movements are planned in an anticipatory fashion. Anticipatory action planning reduces costs for the motor system and optimizes movement control according to current task demands. Movement planning however proceeds not only by a programming of new movements but also by a recall of previous actions. According to the posture-based motion planning model by Rosenbaum, Meulenbroek, Vaughan, & Jansen (2001), previously adopted end postures are stored in memory, recalled, and evaluated according to the current task demands. A goal posture is then selected by retrieving a stored posture from memory. In line with this theorizing, Cohen and Rosenbaum (2004) observed that the end-state comfort effect is reduced when participants move an object from the target position back to the start position, after they moved the object to the target position in the first move. The authors hypothesized that recall of the first move may have served as a template for the next move. Participants recall previously performed actions in order to select an action plan that is most appropriate to reach a current goal. Thus, action planning involves a dynamical prioritizing of both – planning new actions “from scratch” and using previous actions as memory templates for intended similar actions. These processes may also operate in social situations in which people interact and cooperate with other people (Knoblich, Bekkering & Sebanz, 2006).

Effects of Action Observation on Movement Planning

Several research findings suggest that observing another person performing an action affects the planning of an own action. Movement generation is typically facilitated in conditions in which an observed behavior is congruent with the planned action relative to conditions in which an observed action is incongruent with the intended action (Kilner, Paulignan& Blakemore, 2003). Furthermore, research on social imitation suggests a close coupling between acting and observing (Brass, Bekkering & Prinz, 2001). During action observation, the observed action is simulated using the own motor repertoire (e.g. Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; see also Wilson & Knoblich, 2005). This process of action simulation can be very precise, as illustrated by a study by Alaerts,Swinnen and Wenderoth (2010). They found that muscular force requirements of observed actions are encoded by the primary motor cortex, mostly through the perceived kinematics. In line with this research, Castiello, Lusher, Mari, Edwards and Humphreys (2002) reported that observed model grasps facilitate the execution of subsequently performed grasping movements. Participants grasped different objects after observing a model that had grasped either the same or a different object. For this study, it is however unclear whether the movement effect originated from the observed model movement or from the affordance of the perceived object that was manipulated by the model. In fact, Edwards, Humphreys and Castiello (2003) reported that merely perceiving different objects is sufficient to produce an analogous effect, suggesting that action observation is not necessary.

The Present Study

To summarize, there is substantial evidence that perceived actions of others systematically affect the control of one’s own actions. What is less clear, however, is *how* action observation affects subsequent planning of own actions. One possibility is that action observation influences action control directly during action execution (Brass, Bekkering & Prinz, 2001). Another possibility is that action observation affects action control more indirectly through a recall of the observed action. In line with the latter possibility, we hypothesized that observed actions of other people can function as templates for action planning just like one's own actions. More specifically, we investigated whether perceiving a model's end-posture influences the subsequent selection of a grasp location on an object by a participant. Based on the pioneering work of Cohen and Rosenbaum (2004), the present study replicates conditions for an end-state comfort effect in a first movement, as well as a reduction of the end-state comfort effect by means of recall in a subsequent return movement. However, and most crucially, a new condition was introduced in which a model performed the first part of the action sequence instead of the participant. It was expected that observed actions of a model would be recalled and utilized just like one's own actions, extending the recall-effect of Cohen and Rosenbaum to social action observations.

Experiment 1

Like in the study of Cohen and Rosenbaum (2004), participants grasped a vertical plunger with the right hand and moved the plunger to different target fields. The height of the grasp at the home position was measured. We manipulated the height of the target fields so that movements resulted in different end positions. Participants were tested in three conditions: (1) Participants moved the plunger from the home field to the target field (*own action first condition*). (2) Subsequently, they returned the plunger from the target field back to the home field (*own action recall condition)*. (3) Participants watched how a model moved the plunger to the target field and participants moved it back to the home field (*other action recall condition*).

For the *own action first condition*, we expected that the initial grasp height is modulated by the anticipated end-state of the movement: When looking at the particular slope (i.e., the function relating grasp heights to the different target fields), we expected that the initial grasp height is highest for the lower target field and lowest for the higher target field (exhibiting an end-state comfort effect).

For the *own action recall condition* we expected a reduction of the end-state comfort effect due to the previously self-performed movement plan. Based on theory (Cohen & Rosenbaum, 2004), an end-state comfort effect should yield a zero slope in this condition, because all movements are directed at the same end position (the home field). That means, a participant transporting the plunger to the home field should grasp the shaft of the plunger at the same position irrespective of whether the plunger is moved from the higher, lower or middle target field. Given that participants in the *own action recall condition* have already moved the plunger shortly before, a recall of the first plunger movement should affect the next plunger movement, resulting in a reduced end-state comfort effect (as indexed by a non-zero slope).

For the new *other action recall condition*, an analogous reduction of an end-state comfort effect was expected based on the hypothesis that observed actions are functionally equivalent with self-performed actions. Most crucially, participants did not move the plunger from the home field to the target field in this condition; instead, they observed how another person (the model) moved the plunger to a target field. Assuming that observing other´s actions has no influence on the expression of own action planning, a rather flat slope is expected (i.e., a zero-slope). In contrast, a significant deviation from zero would support the hypothesis that the observed model action was used as a template for moving the plunger back to the home field.

Method

Participants

Sixteen participants (14 women) were paid for their participation in the experiment. Participants had an age between 18 and 25 years (M = 23.4). All participants were right-handers.

Apparatus and Stimuli

The apparatus was similar to the one used by Weigelt, Cohen, and Rosenbaum (2007). Figure 1 illustrates the experimental setup. Subjects were to stand on the right and the model on the left of two rectangular pieces of paper (21 cm by 29 cm) that were taped to the floor 36 cm in front of the bookshelf. The bookshelf consisted of three shelves at a height of 50, 85, and 122 cm. A wooden target platform rested on each of the shelves on the right (target shelves), and a platform extended 22 cm from the middle shelf on the left (home shelf). An oversized plunger was placed on the home shelf. Its wooden shaft was 2.5 cm in diameter and 51 cm high, supported by a circular rubber base that was 10 cm in diameter and 5 cm high. Each target shelve could be pulled in and out of the bookshelf, causing it to protrude 22 cm from the edge of the bookshelf. The model was female and 171 cm tall.

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Design and Procedure

Each participant was tested twice with all three target fields in all three conditions (*own action first condition* vs. *own action recall condition* vs. *observed action recall condition*), resulting in 6 trials for each condition (i.e., in total 18 trials for each participant). The order of the conditions was counterbalanced across participants. The order of the target fields was randomized.

Participants gave an informed consent that they are video-taped and that the record is used for a subsequent experiment with another group of participants (cf. Cohen & Rosenbaum, 2004). This cover story explained the presence of a video camera (Sanyo VPC 700 HD, Sony Corporation) that stood on a tripod to the left of the book shelf in full view of the participants. Participants were to follow the instructions of the experimenter, who announced each movement sequence that would be performed. The camera captured the whole length of the plunger on the home platform. A red colored dot was taped to the inner wrist of the right hand of each participant.

Participants were instructed to keep the left hand by their sides at all times and to move the right hand only when instructed by the experimenter. They should hold the plunger firmly in their right hand, and they should move it at a comfortable, unhurried speed from one location to the other.

The sequence of events was identical in each condition. The participant first stepped onto the paper on the right. The experimenter stepped onto the paper on the left and then pulled out one of the three target shelves on the right, indicating the target field. The participant was instructed to grasp the plunger with the right hand to move the plunger to the target field, to set the plunger with the base down, and to return the right hand back to the side of the body.

In the *own action first condition*, the participant moved the plunger from the home field on the left to a target field on the right.

In the *own action recall condition*, the participant grasped the plunger at the target field and returned it to the home field.

In the *other action recall condition*, the model moved the plunger to the target field and the participant returned the plunger to the home field.

To probe suspicion of the experimental manipulation, a post-experimental questionnaire asked (a) whether the participant had noticed anything unusual during the experiment, (b) whether the participant used a strategy or cues when grasping the plunger, and (c) about the purpose of the experiment.

Off-line Video Analysis

Video-taped movements were analyzed following the procedure of Cohen and Rosenbaum (2004, Experiment 2). Two critical movements were identified in each transport cycle: (1) when the participant/model grasped the plunger to move it to the target position. (2) When the participant returned the plunger to the home field. Participants were instructed not to change their hand position after performing a grasp. The position of the hand at the home position hence corresponded with the hand position of the initial grasp.

To assess the grasp heights, the frame of interest for measurement was selected with the program "VLC-Player" (available for free at www.vlc.de). Each data point was stored in a separate picture-file (JPEG-format). A research assistant marked three locations in the image with a computer mouse: (1) the bottom of the plunger, (2) the top of the plunger, (3) and the marker on the wrist of the participant at the moment when the subject/model lifted the plunger from the home platform or returned the plunger to the home field. A macro written in java automatically recorded the marked locations and computed the proportion of the plunger length from the base to the point at which the hand made contact with the plunger (using the program "ImageJ" provided by the National Institutes of Health, http://rsbweb.nih.gov/ij/index.html).

Results

A mixed analysis of variance (ANOVA) with *target field* (low vs. middle. vs. high) and *condition* (own action first vs. own action recall vs. other action recall) as within-factors and the factor *order of condition* as a between factor revealed a significant main effect of *target field*, $F(2, 28) = 63.69$, $p < .001$, $\eta_p^2 = .82$ and a significant main effect of *condition*, $F(2, 28) = 5.133$, $p < .05$, $\eta_p^2 = .268$. The interaction between *target field* and *condition* did not reach statistical significance, $F(2, 28) = 2.264$, $p = .074$, $\eta_p^2 = .139$. Furthermore, the factor *order of condition* did not interact with any of the other factors (*Fs* < 1). Therefore, the data were collapsed across the order factor. Each condition was then analyzed with separate ANOVAs.

Own action first condition

The main effect for target field was significant, $F(2, 30) = 31.78$, $p < .001$, $\eta_p^2 = .679$. As Figure 2 shows, the mean grasp height for the *start-single condition* (solid lines) was inversely related to the height of the target field, showing an end-state comfort effect. When fitting straight lines to the mean values, the best-fitting straight line was -.07 (intercept: 30.9; $r = -.655$, $p < .01$).

Own action recall condition

The main effect of target field was significant, $F(2, 30) = 11.82$, $p < .001$, $\eta_p^2 = .411$. Participants grasped the plunger at different positions, even though the position of the home shelf was constant, with the best-fitting straight line -.05 deviating from zero (Intercept: 27.54; $r = -.987$; $p < .01$).

Other action recall condition

The main effect for target position was significant, $F(2, 30) = 19.98$, $p < .001$, $\eta_p^2 = .571$. As shown in Figure 2 (*other action recall condition* displayed in dashed lines), grasp height was inversely related to the height of the target position. The slope deviated significantly from zero with -.09 (intercept: 31.79; $r = -.549$; $p < .01$), indicating a recall of the model movement. For a direct comparison of both recall conditions, we performed an ANOVA with condition (*own action recall* vs. *other action recall*) as a within factor. This analysis yielded no significant interaction, $F(2, 30) = 2.74$, $p > .05$, $\eta_p^2 = .155$, suggesting similar recall-effects in both conditions.

Model Performance

The grasps of the model were highly consistent, as evidenced by the small standard error of the grasp height (lower field: *M* = 41.12 cm, *SE* = 0.57; middle field: *M* = 27.03 cm, *SE* = 0.27; upper field: *M* = 15.2 cm, *SE* = 0.29). For a further test whether the action of the model was recalled by the participant in the *other action recall condition,* we correlated the grasp height of the model with the grasp height of the participant (using the raw data). As can be seen in Figure 3, there was a significant correlation $r = .56$, $p < .01$. The greater the end-state comfort in the model movement, the greater the reduction of the end-state comfort of the participant.

Post-experimental Questionnaire

None of the participants was suspicious in respect of the model action or the purpose of the study.

-- Please insert Figure 2 and Figure 3 around here –

Discussion

A plunger was moved from a home field to a target field either by the participant or by a model that was observed by the participant. Subsequently, participants moved the plunger from the target field back to the home field. In the *own action first condition*, participants showed an end-state comfort effect. When they moved the plunger to the upper field, the plunger was grasped at a low height; in contrast, the plunger was grasped at a high height when the plunger was moved to the lower target field. In the subsequent *own action recall condition,* participants showed a reduced end-state comfort effect, suggesting that participants recalled their previous movement and that they used this memory trace for the generation of a new action plan. These findings for the *own action first* and the *own action recall condition* are in line with Cohen and Rosenbaum (2004), replicating their results.

More important for the present discussion, a reduced end-state comfort effect was also observed in the new *other action recall condition.* This result is striking, given that participants have only passively observed a model performing the first part of the movement sequence in this condition. An influence of the observed action on the participants' actions is also supported by a significant correlation between the grasp height of the model and the grasp height of the participant: The higher the model grasp during the first movement to the lower target field, the higher was the plunger grasped by the participant when returning the plunger back to the home field. A reverse pattern was observed when the model moved the plunger to the higher target field. This correlation is in line with the idea that participants have recalled and imitated the model action.

A possible limitation to this finding is that participants may have used action observation for own action planning only because the actions of the model were somehow ambiguous in respect to the planning constraints. In fact, the discomfort produced by the end-states of the movements in the recall conditions was relatively mild, because the middle position was easy to reach. Experiment 2 therefore investigated whether participants use a model action for own action planning when the observed action is more incompatible with the intended movement.

Experiment 2

Participants observed how a model moved a plunger from a new platform on the left side of the shelf to the home field. Subsequently, they moved the plunger from the home field either to the upper or the lower target field. In addition, the way how the model grasped the plunger was manipulated systematically, resulting in a low or high grasp along the shaft of the plunger.

In line with Experiment 1, it was expected that the initial grasp height of the participants is modulated by the anticipated end-state of the movement and that participants exhibit an end-state comfort effect. Furthermore, the observed model action was compatible with an end-state comfort grasp of the participant (i.e., a placement of the plunger on the lower [higher] target field after the observation of a high [low] model grasp) or incompatible (i.e., a placement of the plunger on the lower [higher] target field after the observation of a low [high] model grasp). It was expected that the observation of a congruent model grasp should increase end-state comfort, while the observation of an incompatible model grasp should decrease end-state comfort.

Method

Participants

Seventeen participants (13 women) were paid for their participation in the experiment. Participants had an age between 20 and 31 years (*M* = 25.5). Handedness was measured with the Edinburgh Handedness Inventory (Oldfield, 1971). All participants were right-handers (Mean Edinburgh Handedness Inventory index: 63.24)

Apparatus and Stimuli

The apparatus was the same as in Experiment 1 with the exception that an additional platform (height 85 cm) was placed on the left side of the shelf (see Fig. 1). There were two potential target shelves (height 50 cm or 122 cm) but no middle target shelf. The model in Experiment 2 was male and 186 cm tall.

Design and Procedure

The general procedure was similar to the *other action recall condition* in Experiment 1 with one major change: At the start of a trial, the plunger rested on a shelf on the left side of the home shelf. The participant first stepped onto the paper on the right and the experimenter stood on the paper on the left. The experimenter then pulled out one of two target shelves on the right, indicating the target field. The model moved the plunger from the model's shelf to the home shelf. Crucially, the model grasped the plunger at one of two designated positions (low vs. high grasp of plunger). Then, participants moved the plunger from the home shelf to the designated target shelf. Compatibility was coded in respect to the observed model grasp (high vs. low) and the target shelf height affording an end-state comfort grasp of the participant (high vs. low). Movement instructions were the same as in Experiment 1.

Off-line Video Analysis

Videos were analyzed as in Experiment 1.

Results

The grasp height of the model was highly consistent (lower grasp: *M* = 40.41 cm, *SE* = 0.48; upper grasp: *M* = 18.13 cm, *SE* = 1.7).

End-state Comfort Effect

A repeated-measures ANOVA of the grasp heights with *target field* (low vs. high) and *compatibility* (compatible vs. incompatible) as factors revealed a significant main effect of *target field*, $F(1, 17) = 17.43$, $p < .001$, $\eta_p^2 = .521$. Participants grasped the plunger at a lower height (*M* = 25.57 cm) when they moved the plunger to the high target field compared to when the moved the plunger to the high target field (*M* =29.71 cm). This finding confirms an end-state comfort effect.

Furthermore, the main effect of *compatibility* was significant, $F(1, 17) = 13.53$, $p < .01$, $\eta_p^2 = .458$. Thus, the grasp height of the model systematically affected the grasp height of the participant. This finding was further qualified by an interaction between *target field* and *compatibility*, $F(1, 17) = 5.81$, $p < .05$, $\eta_p^2 = .266$. Follow-up tests revealed that the effect of *compatibility* was only significant for the lower target field. As shown in Figure 4, observation of compatible relative to incompatible model grasps enhanced end-state comfort when the plunger was moved to the lower target field, $t(16) = 4.57$, $p < .001$, $d = 1.11$, but not when the plunger was placed onto the higher target field ($t < 1$).

Post-experimental Questionnaire

Four participants were suspicious in respect to the model action, stating that the purpose of the study was somehow related to the observation of the model. To control for demand characteristics, analyses were repeated after exclusion of the suspicious participants. These analyses yielded analogous results.

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Discussion

In Experiment 2, participants initial grasp height of a plunger was inversely related to the height of the target field, showing an end-state comfort effect. Importantly, observing how a model grasped a plunger affected how the participant grasped the plunger for an own movement: Observation of a model grasp compatible with a comfortable end-state increased end-state comfort, while the observation of an incompatible model grasp decreased end-state comfort. These results are in line with the hypothesis that observed actions are used as templates for planning an own action even when the template is suboptimal for own action planning (in terms of a comfortable end-state).

It should be noted, however, that the model grasp influenced end-state comfort only when the participant moved the plunger to the lower target field. It is possible that adopting an incompatible, high grasp position in order to place the plunger on the upper target field incurred higher costs than adoption of an incompatible incongruent grasp at the lower target field. This explanation is plausible given that upright body postures are strongly limited by body height. Further research is necessary to investigate a possible limitation by body height.

Although the observation of compatible and incompatible model actions influenced the size of an end-state comfort effect, observing an incompatible model action did not eliminate or reverse this effect. This outcome finding is unsurprising given that a recall of observed actions is only one of several constraints on a comfortable end position. Indeed, theorists have proposed that end-state comfort involves a flexible hierarchy of planning constraints that are weighted differently depending on the task setting (van der Wel & Rosenbaum, 2010).

General Discussion

This study examined whether people use observed actions of another person as templates for own action planning. Results showed that participants grasped a plunger a higher (lower) position after having observed a model that grasped the plunger at a higher (lower) position (Experiment 1), even if the observed grasp was incongruent with a comfortable end position (Experiment 2). These results support the idea that an observer simulates in his own brain the action he observes another person performing, and that the motor representation for that action is used as a template for own action planning (Gallese & Goldman, 1998; Jeannerod, 2006).

Reusing observed actions facilitates action planning when the observed action is congruent with an intended action. However, they can produce interference when they are in conflict with one's goals. How can agents benefit from action observation while minimizing interference? A hint for a possible answer to this question comes from a study by Meulenbroek, Bosga, Hulstijn, and Miedl (2007). Dyads transported objects of different size and weight in a shared workspace. People typically expect larger objects to be heavier in comparison with smaller objects of the same mass (the so-called *size-weight illusion*, Charpentier, 1891). The resulting surprise effect can then be measured in the kinematics of the transport movement. In this study, the sequential structure of the task allowed a member of the dyad to observe the other member moving an object before moving the object on their own. Results showed that the surprise effect induced by the seize-weight illusion was reduced for the second person (i.e., the observer). The observer did not simply copy the observed action for own action planning but, rather, inferred the actual weight of the object from the observed kinematics. This study nicely demonstrates that templates derived from action observation are adapted to the affordances of the current task.

The posture-based motion planning model by Rosenbaum and colleagues (2001) can account for a flexible and adaptive integration of action recall and generation. According to this account, action planning proceeds in two stages: In a first recall phase, a goal posture is identified from a set of stored postures and retrieved from memory. The memorized posture is then adapted to the affordances of the present task in a subsequent movement generation phase. If actions of others are memorized in the same way as self-generated actions, this knowledge can be used for observational learning (Bandura, 1986) and to coordinate actions with social interaction partners (Sebanz & Knoblich, 2009; Meyer, van der Wel & Hunnius, 2013).

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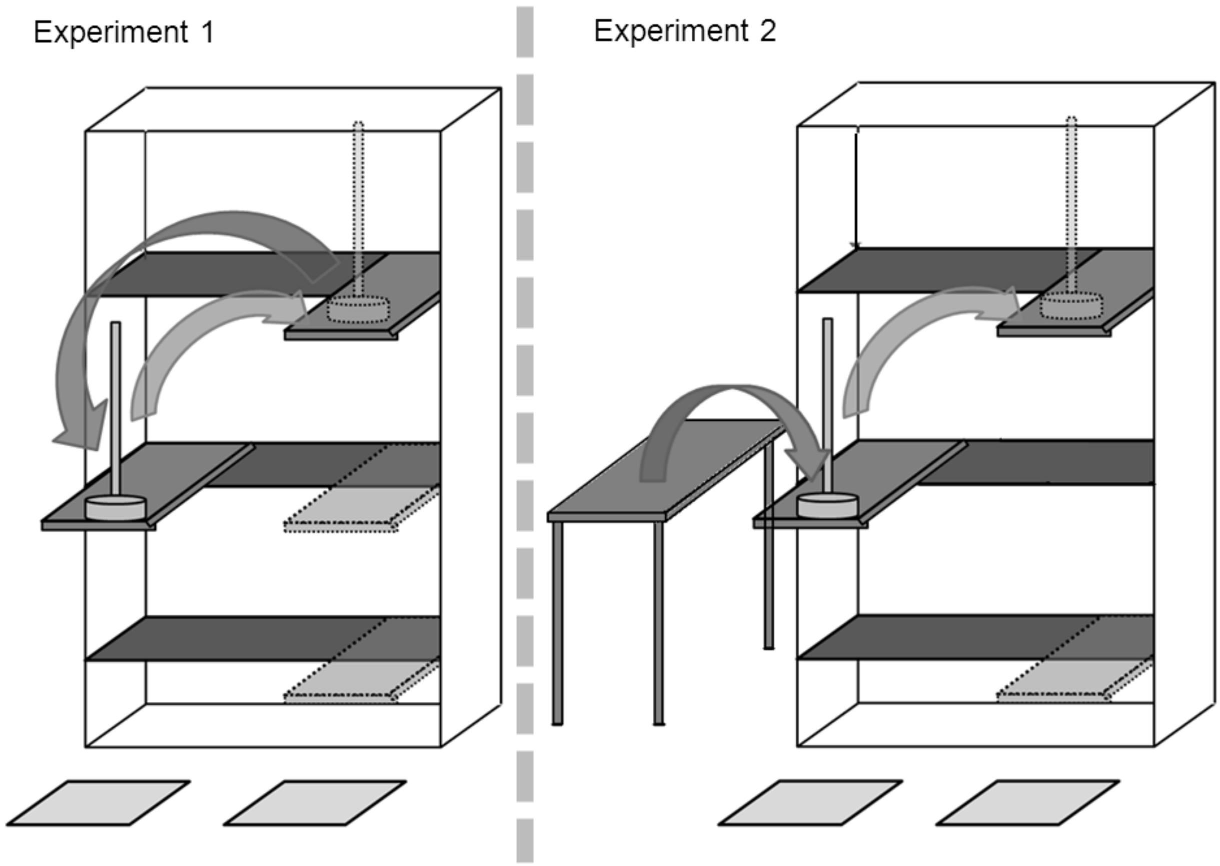

Figure 1. Setup used in Experiment 1(left panel): Participants always stood on the right plate. The plunger was moved from the home field (on the left) to one of three target fields (low, middle, and high fields on the right side). This movement comprised the *own action first condition* (light grey arrow). Subsequently, they returned the plunger from the target field to the home field *(own action recall condition,* dark grey arrow*).* In the *other action recall condition,* a model standing on the left plate moved the plunger to the target field, and the participant moved it back to the home field (light grey arrow).

Setup used in Experiment 2 (right panel): The model grasped a plunger at a low or high height and placed the plunger on the home shelf of medium height (dark grey arrow). Participants then moved the plunger from the home shelf to the lower or upper target field (light grey arrow).

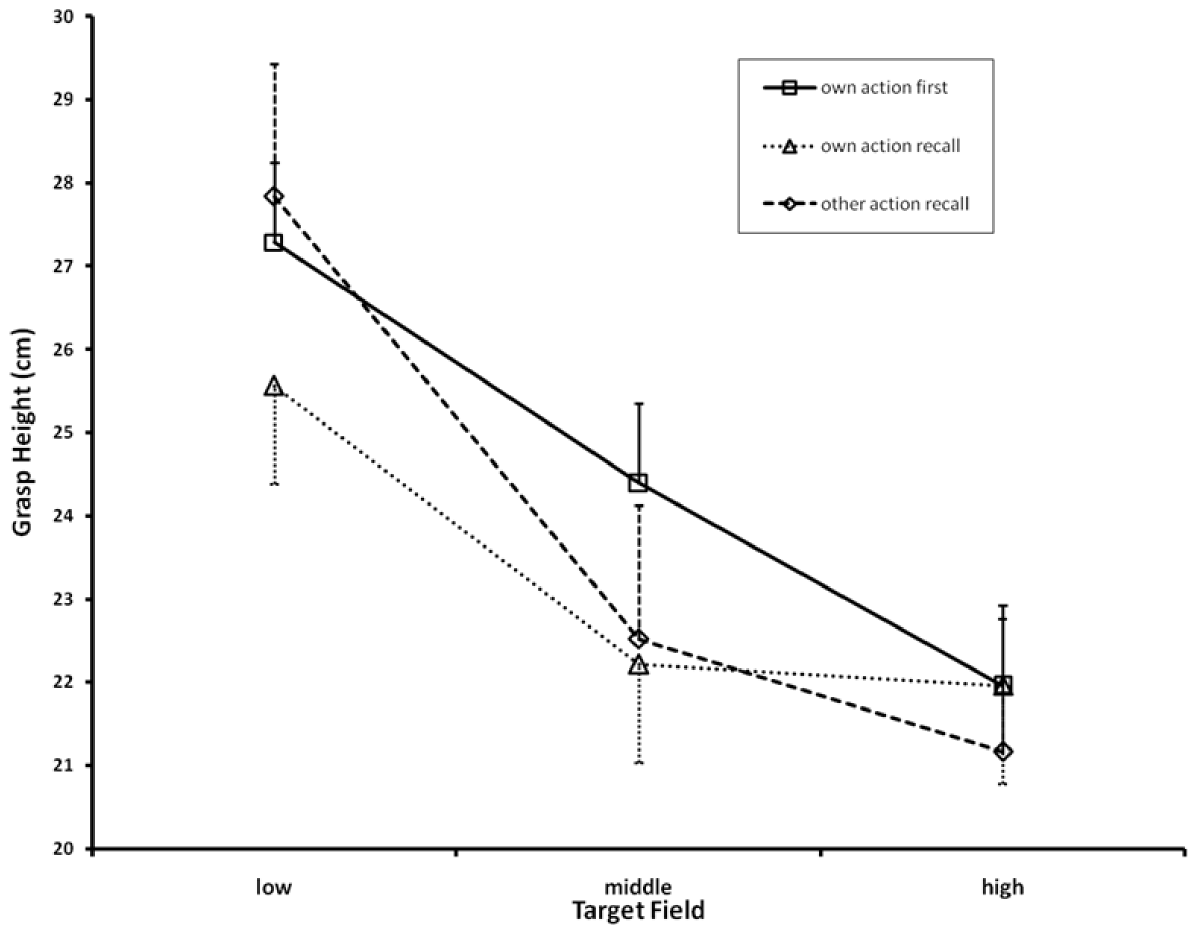

Figure 2. Mean grasp height as a function of target field for the three conditions (*own action first condition, own action recall condition* and *other action recall condition).* Error bars indicate 95% within-subject confidence intervals (see Loftus & Masson, 1994 for details).

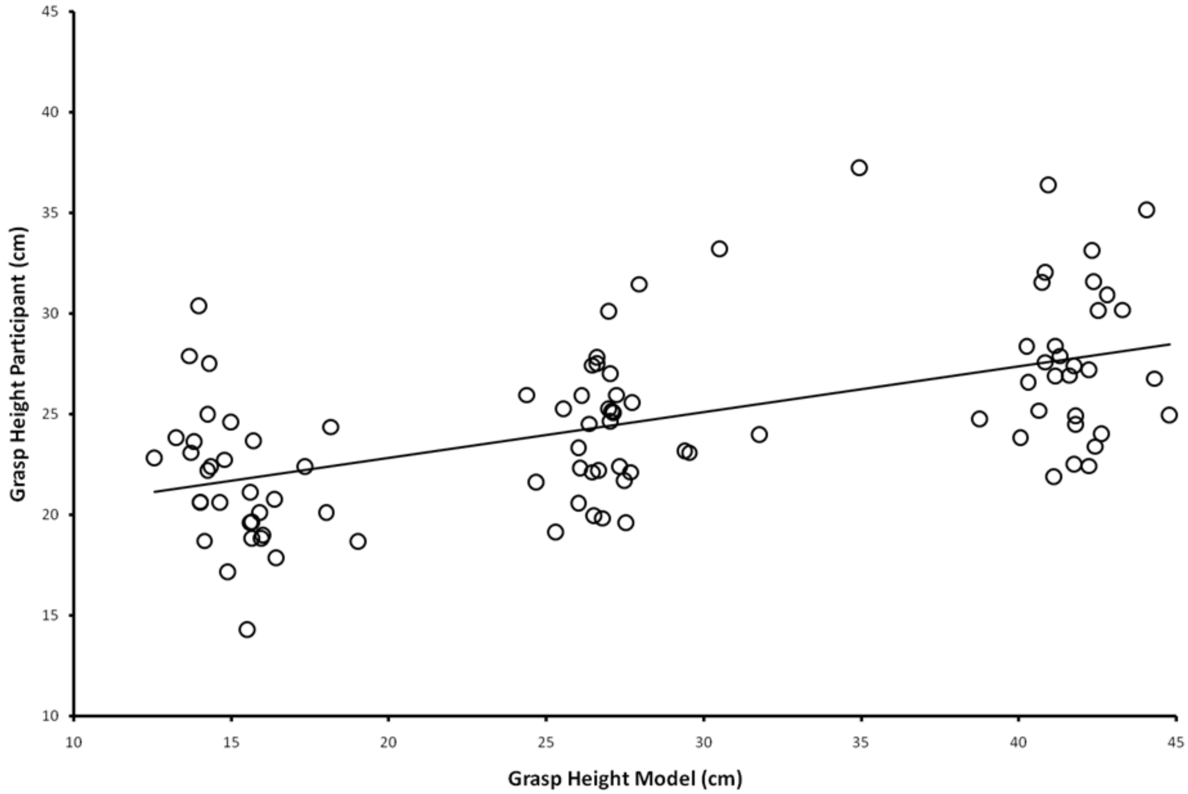

Figure 3. Correlation between the grasp heights of the model and the grasp heights of the participants.

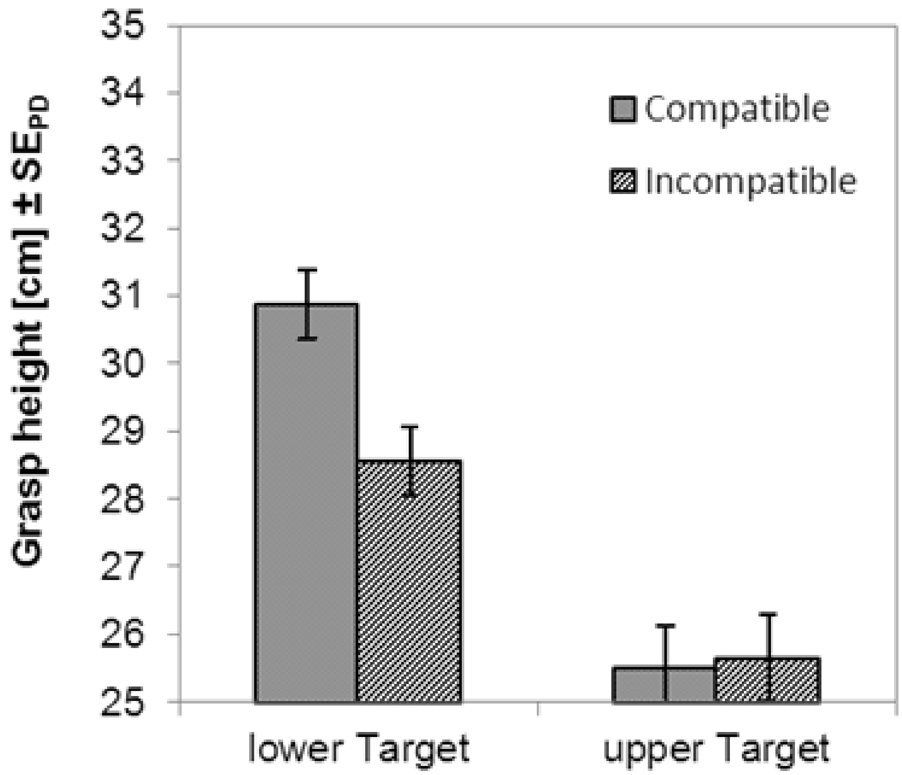

Figure 4. Mean grasp height in Experiment 2 as a function of target field and compatibility of model actions. Error bars indicate the standard error for paired differences (see Pfister & Janczyk, 2013 for details).