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From Conscious Thought to Automatic Action: A Simulation Account of Action Planning

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We provide a theoretical framework and empirical evidence for how verbally planning an action creates direct perception-action links and behavioral automaticity. We argue that planning actions in an if (situation)–then (action) format induces sensorimotor simulations (i.e., activity patterns reenacting the event in the sensory and motor brain areas) of the anticipated situation and the intended action. Due to their temporal overlap, these activity patterns become linked. Whenever the previously simulated situation is encountered, the previously simulated action is partially reactivated through spreading activation and thus more likely to be executed. In 4 experiments ($N = 363$), we investigated the relation between specific if–then action plans worded to activate simulations of elbow flexion versus extension movements and actual elbow flexion versus extension movements in a subsequent, ostensibly unrelated categorization task. As expected, linking a critical stimulus to intended actions that implied elbow flexion movements (e.g., grabbing it for consumption) subsequently facilitated elbow flexion movements upon encountering the critical stimulus. However, linking a critical stimulus to actions that implied elbow extension movements (e.g., pointing at it) subsequently facilitated elbow extension movements upon encountering the critical stimulus. Thus, minor differences (i.e., exchanging the words "point at" with "grab") in verbally formulated action plans (i.e., conscious thought) had systematic consequences on subsequent actions. The question of how conscious thought can induce stimulus-triggered action is illuminated by the provided theoretical framework and the respective empirical evidence, facilitating the understanding of behavioral automaticity and human agency.

Keywords: human agency, planning, control, automaticity, grounded cognition

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The question of whether and how the mind controls the body (i.e., the issue of mental causation) has engaged human curiosity, speculation, and scientific research throughout human history. Our subjective experience favors a Cartesian mind–body dualism in which the mind selects an action and causes the body to perform it. Deviations from this sense of agency are mostly perceived as mental disorders (e.g., *anarchic hand syndrome*, Sala, 1998; *utilization behavior*, Frith, Blakemore, & Wolpert, 2000; Jeannerod, 2009; Lhermitte, 1983). This mental-causation perspective, however, is largely incompatible with neuroscientific evidence implying that conscious experiences (and thus also conscious intentions to act) are consequences—rather than antecedents—of brain activity (Haggard & Eimer, 1999; Libet, Gleason, Wright, & Pearl, 1983; Soon, He, Bode, & Haynes, 2013). This research raises the question of whether conscious thoughts (e.g., intentions to act) are causally involved in action generation at all or whether they are merely an epiphenomenal consequence of subconscious action generation and execution (see Jordan, 2013, for a detailed discussion).

In the present work, we address this conflict between apparent mental causation and modern neuroscientific evidence by investigating a specific type of thought, if–then action plans (*implementation intentions*, Gollwitzer, 1999), and their effects on subsequent action. We will provide a theoretical perspective of how an agent's thought in this specific format instigates perceptual- and motor-related brain activity which establishes a direct perception-action link. This direct link allows the intended action to be

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triggered upon perceiving the anticipated situation without higher-order cognitive contributions. Empirically, we will demonstrate how manipulating minimal aspects of one's action plan (i.e., thought content) has systematic behavioral consequences upon encountering the anticipated situation. Our approach demonstrates the mental causation of action and provides an explanation that is in line with modern neuroscientific evidence.

How Thought Creates Perception-Action Links

Based on simulation theories of cognition (Barsalou, 1999, 2010), recent theoretical developments indicate that comprehending language is a result of reactivated experiences in the form of sensorimotoric simulations in the brain (Glenberg, 2007; Kiefer & Pulvermüller, 2012; Zwaan, 2004). For example, understanding the word *bicycle* would entail the reactivation of past sensory and motor experiences (e.g., visual images, sounds, leg movements). These simulations in modal brain areas (i.e., sensory and motor areas) provide the basis for understanding the word "bicycle" beyond comprehension derived from the mere appearance of the letters. Various neuroscientific studies have found evidence for modality-specific brain activation when processing language in perceptual (González et al., 2006) and motor areas (Hauk, Johnsrude, & Pulvermüller, 2004). Importantly, some evidence has been provided in favor of a causal role of motor areas in language comprehension (Glenberg & Kaschak, 2002; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005; but see Papesh, 2015, for a critical discussion). This hypothesized grounding of a higher cognitive function like understanding language in modal brain areas not only provides a basis for explaining the comprehension of concepts in the absence of the actual physical referent (Barsalou, Simmons, Barbey, & Wilson, 2003), but also how language can be used strategically to activate specific perceptual and motor simulations in respective brain areas. This new idea is fundamental to the present work; we will return to it after introducing if–then action planning in more detail.

Empirical research supports the effectiveness of verbally formulated if–then plans in initiating intended actions (summarized in Gollwitzer, 2014; Gollwitzer & Sheeran, 2006). Such if–then action plans specify an anticipated situation and link it to an intended action (e.g., "*If I pass by the drugstore, then I will pick up my medicine!*"). Consequences of these plans include a perceptual readiness to detect the anticipated situation (Achtziger, Bayer, & Gollwitzer, 2012; Parks-Stamm, Gollwitzer, & Oettingen, 2007; Wieber & Sassenberg, 2006) and an initiation of the intended action with characteristics associated with a direct perception-action link (i.e., *fast*, Cohen, Bayer, Jaudas, & Gollwitzer, 2008; *efficient*, Brandstätter, Lengfelder, & Gollwitzer, 2001; and *without an in situ conscious intention*, Bayer, Achtziger, Gollwitzer, & Moskowitz, 2009). Our current theorizing aims to close a gap between the evidence provided about the effectiveness of if–then action planning (i.e., its cognitive and behavioral consequences) and the critical question of how a verbal plan (i.e., conscious thought) creates a direct perception-action link.

Simulation theories of language comprehension (e.g., Kiefer & Pulvermüller, 2012) suggest that formulating an if–then plan in self-directed or inner speech should be accompanied by a perceptual simulation of the anticipated situation (e.g., exterior of the drugstore) and a motor simulation of salient aspects of the intended action (e.g., stopping and turning to enter the store). In line with the basic principle of "what fires together wires together," the temporal overlap for the specific sensory and motor states, activated by thought, should result in their integration (Hebb, 1949).

Thus, our basic proposal is that if language is grounded in modal simulations, then forming a verbal if–then action plan links specific neural activity patterns in perceptual brain areas representing the anticipated situation with specific neural activity in motor areas representing the intended action. Action planning in an if–then format thereby creates a basic perception-action link between perceptual and motor areas. Upon encountering the anticipated situation, this associative link between the situation and the action should activate the action-relevant brain activity and thus increase the likelihood and the speed of executing the intended action. Thus, an agent who is knowledgeable about the consequences of linking an intended action to an anticipated situation can strategically use language-based thought to heighten the probability of performing a desired action in the future (Martiny-Huenger, Martiny, & Gollwitzer, 2015). Prior theorizing has focused on creating this type of link by the repeated actual perception of a certain situation paired with the actual execution of a certain action (*habitual action control*; Wood & Neal, 2007). Our research and the theoretical framework explores the possibility of establishing such links in the absence of the actual situations and actions by conscious thought alone.

The Current Studies

The current studies test specific aspects of our hypothesis that situation-action links can be created in one's mind and, at the same time, we provide evidence that language-based thought unobtrusively affects subsequent actions. With a behavioral paradigm, we can only indirectly approach and test the simulation hypothesis, relying on our intuitions of what salient motor components are included in a specific verbally formulated action (e.g., "I will grab an apple"). In if–then planning research, specific behaviors are typically specified by the experimenter, and these exact behaviors are then measured (e.g., the effectiveness of the plan including "then I will press the left button" is measured by response times of pressing the left button, Cohen et al., 2008). In the present studies, we induced action planning of a mundane behavior (i.e., grabbing an apple, pointing at an apple) to later assess a specific behavioral component that we expected to be included in the simulation of the action, but that was not explicitly stated in the verbal formulation. From the simulation hypothesis of language comprehension (e.g., Barsalou, 1999; Kiefer & Pulvermüller, 2012), we deduced that the simulation of a specific action includes certain salient components represented by respective patterns of activity in motor brain areas. These salient motor components should then be integrated with the coactivated pattern representing the critical situation in perceptual areas.

For the action of "grabbing an apple" for consumption, we expected that a very salient simulation component is the elbow flexion (pull) movement. This is the case because the elbow flexion movement is the most important and temporally closest motor component of simulating the action toward the intended effect (i.e., consumption; biting into the fruit). In contrast, we expected a salient component of "pointing at an apple" to be an elbow extension (push) movement. This is the case because for simulating this action toward the intended effect (i.e., pointing at something in the environment) an elbow extension movement is necessary. In sum, we expected the simulation of "grabbing an apple" to be more likely to entail an elbow flexion (pull) movement compared with the simulation of "pointing at an apple" which would entail an elbow extension (push) movement. Because of the temporal overlap of the motor simulation with the critical cue (e.g., apple), the patterns should be integrated and the activation of one of them (e.g., perceiving an actual apple) should facilitate the reactivation of the other (e.g., salient motor component of the respective intended action).

Thus, in our studies (see Figure 1), participants started by setting themselves the goal to eat more healthy food, and then chose one particular fruit that they intended to eat more often. During a planning phase, they formulated an action plan to either *grab* or *point at* the chosen type of fruit (e.g., apple; "If see an apple, then I will *grab/point at* it immediately"). In a subsequent test phase not ostensibly related to the planning session, participants categorized different pictures as either fruits or vegetables. Responses in this timed categorization task were performed with a joystick that either had to be pushed away from or pulled toward the participant's body, thereby including an elementary elbow extension or elbow flexion movement, respectively. We hypothesized that the respective motor simulation would be linked to the perceptual simulation of the anticipated situation (e.g., apple) in the planning phase. Subsequently encountering the apple should partially reactivate the respective motor component. We predicted that after planning to *grab* versus *point at* a specific fruit, encountering that fruit in the test phase's categorization task would facilitate pull versus push responses, respectively. We have conducted four studies to test these predictions, and we report all of them here. We examined a "grab" plan ("If I see a(n) [critical fruit], then I will grab it immediately") in Studies 1, 2, and 4, and a "point" plan ("If I see a(n) [critical fruit], then I will point at it immediately") in Studies 3 and 4.

Study 1: Triggering Elbow Flexion Movements

In Study 1, all participants set themselves the goal of eating more of a particular type of fruit and formulated the if–then action plan "If I see a(n) [critical fruit], then I will grab it immediately." After this planning phase, the participants categorized different pictures as either fruits or vegetables in the push-pull categorization task by pushing or pulling a joystick toward or away from themselves, respectively. The response times to enact these basic elbow flexion versus elbow extension movements served as the dependent variable. The critical fruit was expected to trigger an elbow flexion movement and thus facilitate this response compared with elbow extension responses to the critical fruit. For responses to the control stimuli we expected no differences between elbow flexion and extension responses as they should not be systematically associated with either movement.

Method

Participants and design. Fifty-four students (41 female/13 male) of a German university participated in this study. In line with the universities ethical standards, all participants gave verbal, informed consent to participating in the study and participants and data were treated according to APA's Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2010). Their mean age was 23.481 (SD = 4.129) with a range from 19 to 43. The design followed a 2 (Stimulus Type: critical fruit vs. control) × 2 (Response: push vs. pull) within-participant design with the logarithmized joystick response times in the push-pull categorization task as the dependent variable.

Goal setting and planning phase. All instructions and questions were presented on a computer screen. Participants were informed that the experiment was about goal setting with respect to eating fruit. They were told that they would be presented with information about why eating fruit is good for them and that they will be asked to set themselves the goal to eat more of a particular kind of fruit. Then they were told that in order to make this goal more relevant to them they had to select one of six pictured types

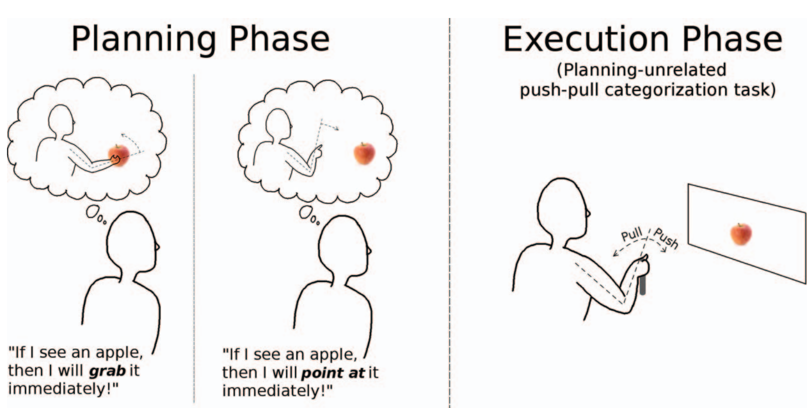

Figure 1. Conceptual representation of the four studies' procedure. In the planning phase participants either memorized and committed to a "grab" plan (Studies 1, 2, and 4) or a "point" plan (Studies 3 and 4), including their self-chosen critical fruit (e.g., apple) and the action of grabbing versus pointing at it, respectively. In the execution phase, participants categorized food items as fruits or vegetables by either pushing a joystick toward the stimulus or pulling it toward themselves, respectively. See the online article for the color version of this figure.

of fruit to eat more often (apple, banana, grapes, kiwi, orange, pineapple). Each participant's chosen fruit is called *critical fruit* throughout the article. After the participant's fruit choice, the actual goal setting and action planning started. Participants were presented with their personal—adapted to their fruit choice— goal ("*I want to eat more* [critical fruit]") and their personal—adapted to their fruit choice—if–then plan ("*If I see a(n)* [critical fruit], then I will grab it immediately") and asked to memorize it. To consolidate the memorization, after the initial presentation each participant was presented with the goal and the if–then action plan two more times and asked to repeat the goal and plan silently to themselves. The three memorization phases were separated by two short distraction tasks; one included a quiz about nutrition and the other involved reading a short paragraph about healthy nutrition. Finally, participants' goal commitment was measured with four items ("It is difficult to take the goal to eat more [critical fruit(s)] seriously," [reverse coded]; "I believe that eating more [critical fruit(s)] is an important goal," "Honestly, I do not care whether I reach the goal of eating more [critical fruit(s)]," [reverse coded]; "I feel committed to reaching the goal of eating more [critical fruit(s)]."). Responses were collected on a 7-point scale with the anchors *do not agree* and *agree*. A Cronbach's alpha of 0.646 indicated a low but acceptable internal consistency and the mean of 4.870 (SD = 1.043) indicated a moderately high average goal commitment.

Test phase: Push-pull categorization task. Each participant completed two blocks of 144 categorization trials each presented using Psychopy (Peirce, 2009). In each trial, after a fixation cross (600 ms) and a blank screen (300 ms), one stimulus was presented and the participant categorized it as either fruit or vegetable. Responses were made by moving a joystick (model: Logitech Attack 3) mounted in between the participant and computer screen either toward the participant's body (pull/elbow flexion) or toward the screen (push/elbow extension). The joystick had to be deflected by 80% of its total range to count as a response and the next trial was initiated only after the joystick had been returned to the starting position. Each stimulus was presented until the response occurred or 5,000 ms had passed, in which case the respective trial counted as an error. In the case of a response error or slow response (>2,300 ms), feedback was presented that the current response was wrong or to try to respond faster, respectively.

The stimulus material consisted of six different pictures each of six different fruits (apple, banana, grapes, kiwi, orange, and pineapple) and vegetables (carrot, cauliflower, cucumber, onion, pepper, and radish). Thus, 72 different stimulus pictures were presented twice in each of the two blocks of 144 trials. The only difference between the two blocks was the reversal of the push/pull response assignment to the fruits and vegetables. The order of this assignment was counterbalanced between participants. Six practice categorization responses were made by the participants under the supervision of a research assistant to ensure a proper understanding of the task and the correct operation of the joystick (e.g., to ensure full arm movements instead of just wrist movements). After the test phase, participants completed a computerized questionnaire with study-related questions including their dominant hand, which hand they used to operate the joystick, what they thought the purpose of the study was, and demographics like gender and age.

Data treatment and analysis approach. Participants who operated the joystick with their nondominant hand were excluded from the data analysis (n = 4). The remaining 49 right-handed and 2 left-handed participants operated the joystick with their respective dominant hand. Furthermore, one participant was identified as an outlier (Tukey, 1977) on the push-pull categorization task with an error rate of 6.250% as compared with the total sample's mean error rate of 1.961% (SD = 1.387), and was therefore excluded from the analyses. With regard to individual trials, all trials with an erroneous response (i.e., incorrect categorization or failure to respond within 5,000 ms) were excluded from the analyses (1.875% of the trials). Furthermore, trials with response times lower than 200 ms and response times exceeding 3 standard deviations above the mean (calculated separately for each participant and the within-participant factors stimulus type and response) were excluded from the analyses as well (1.352% of the trials).

To analyze the data and produce the plots, the open source software *R* (R Core Team, 2014), *lme4* (Bates, Mächler, Bolker, & Walker, 2015), and *lsmeans* (Lenth, 2015) on top of a Debian linux operating system (Debian Developers, 2016) was used. We performed linear mixed effects analyses to assess the relationship between our experimental factors and the log-transformed response times (Judd, McClelland, & Culhane, 1995; Ratcliff & Murdock, 1976) from the push-pull categorization task. As log-transformed data is hard to interpret, in line with common convention, all graphs depict the nontransformed condition means in milliseconds. As fixed effects, we entered stimulus type, response, and their interaction terms into the model. As random effects, we entered intercepts for participant and all factors nested in participant (response assignment block, stimulus type, stimulus item, response). Effect sizes for the relevant interaction models were calculated as suggested by Xu (2003). Response errors were analyzed using the same linear mixed model approach but adapted for binomial data. p values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect. Post hoc comparisons were obtained by least-squares means predicted from the full model, with a p value adjustment for multiple comparisons by using the Tukey method.

Results

As expected, the analysis of the response times from the push-pull categorization task showed a significant stimulus type by response interaction effect, $\chi^2(1) = 14.887$, $p < .001$, $\Omega_0^2 = .246$ (Figure 2a). The same linear mixed-model analysis performed on the response errors showed no significant stimulus type by Response interaction effect, $\chi^2(1) = 2.531$, $p = .112$ (Figure 2a), and thus no substantial evidence for a speed–accuracy trade-off. Therefore, we proceeded to analyze the response time pattern; in line with our prediction that the grab plan should facilitate pull responses to the critical stimuli, individual contrasts showed that the critical-pull responses (M = 640.435 ms, SD = 64.844 ms) were faster than all other conditions: critical-push (M = 668.297 ms, SD = 73.581 ms), neutral-pull (M = 663.745 ms, SD = 55.967 ms), and neutral-push (M = 667.185 ms, SD = 52.239 ms), all ps < .001.

Although not statistically significant, the response-error pattern was in the direction of a speed–accuracy trade-off. To rule out this explanation, we performed an additional analysis including only participants who made an equal number of errors on critical-pull and critical-push responses (38 out of 50 participants; 76%). In this

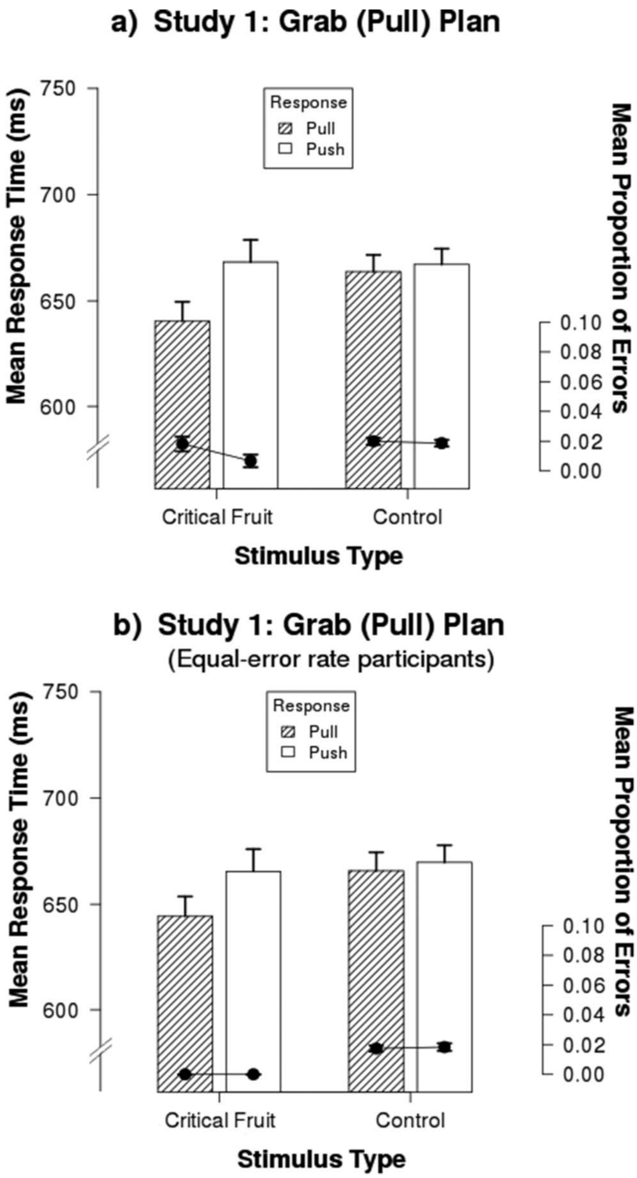

Figure 2. Mean response times (+*SEM*) and mean error rates per stimulus type and response condition. Figure 2a displays the results for all participants and Figure 2b the results for the majority of participants (76%) who showed an equal error rate for push and pull responses to the critical fruit stimuli.

majority subset we can exclude a speed–accuracy trade-off. This analysis confirmed our initial results by showing a similar significant stimulus type by response interaction effect, $\chi^2(1) = 6.506$, $p = .011$, $\Omega_0^2 = .232$ (Figure 2b). In sum, our findings provide first evidence that planning to grab a particular (edible) object facilitated previously simulated elbow flexion movements—an important part of executing the planned action—upon perceiving the object.

Study 2: Facilitated Versus Inhibited Actual Movement During Planning

In Study 2, we aimed to replicate the results found in Study 1. Thus, again, all participants set themselves the goal of eating more of a particular type of fruit and formulated the if–then action plan "If I see a(n) [critical fruit], then I will grab it immediately" before completing the push-pull categorization task. Furthermore, we included two critical additions to further validate our conclusion that the conscious action planning was driving the behavioral effects found in Study 1.

First, to provide evidence that actual movements during planning were not responsible for the effect in Study 1, we unobtrusively controlled participants' arm movements in Study 2 during the planning phase, either by *inducing* both flexion and extension elbow movements (pushing against an elastic fitness band with the arms and releasing it; arm movement condition) or by *impeding* actual elbow movements (no arm movement condition). The *no arm movement* condition was indirectly induced by a leg movement (pushing against an elastic fitness band with the feet) which was only possible by fixating oneself with the hands on the chair or table. Thus, while keeping the motoric cognitive load comparable, performing the leg movement prevented the participants from making the actual arm movements involved in the intended action. As we did not expect actual arm movement to be necessary nor hindering, we predicted a replication of the results of Study 1 in both conditions.

Second, we included liking ratings of the six fruit types in the final questionnaire to assess whether liking of the critical fruit can account for potential response time differences between the critical versus neutral stimuli and the push versus pull responses. For example, liking of a critical stimulus may facilitate approach movements (Chen & Bargh, 1999; Eder & Rothermund, 2008) which—depending on how the participants construe the situation—may manifest itself in a pull movement (e.g., approaching the fruit by pulling it closer). By assessing liking ratings of the critical fruit, we aimed to demonstrate that liking cannot account for the pull facilitation for the critical fruit.

Method

Participants and design. One-hundred and four students (76 female/28 male) of a German university were randomly assigned to one of the two between-participants conditions of the study. Their mean age was 22.913 ($SD = 3.223$), ranging from 19 to 37. The design followed a 2 (Movement, between: arm movement vs. no arm movement) × 2 (Stimulus Type, within: critical fruit vs. control) × 2 (Response, within: push vs. pull) model design with the joystick response times in the push-pull categorization task as the dependent variable.

Procedure. Study 2 followed the same procedure as Study 1 with two differences: During the planning phase, whenever (and only when) the participants were presented with their personal goal and action plan, they performed a flexion and extension movement with either their arm or their legs, depending on condition. Arm movements were performed with an elastic fitness band that was wrapped around the back of the participant's chair with the two ends held in the participant's hand. Participants steadily extended and released their arm toward the screen while reading and memorizing the goal and action plan. For the *no arm movement* condition, an elastic fitness band was mounted between the front legs of the participant's chair. Participants steadily pushed and released their legs against the band, balancing on their seat by leaning on their hands. This inhibited actual plan-mimicking arm actions. A signal of when to start and stop the movement was given immediately before and after the instruction screens containing the goal and the plan. Second, the final questionnaire additionally contained liking ratings (7-point scale) of all six types of fruit presented during the experiment including the critical (previously chosen) type of fruit.

Data treatment. The data was treated in the same way as in Study 1. Participants who did not operate the joystick with their dominant hand ($n = 6$) were again excluded from the data analysis. The remaining 92 right-handed and 6 left-handed participants operated the joystick with their respective dominant hand in the push-pull categorization task. Furthermore, four participants were identified as outliers (Tukey, 1977) on the push-pull categorization task with error rates of 7.986%, 11.806%, 15.278%, and 15.625% as compared with the total sample's mean error rate of 3.019% (SD = 2.671%), and were therefore excluded from the analyses. With regard to individual trials, all trials with an erroneous response (i.e., incorrect categorization or failure to respond within 5,000 ms) were excluded from the analyses (2.608% of the trials). Furthermore, trials with response times lower than 200 ms and response times exceeding mean response time plus three times the standard deviation (calculated separately for each participant and the within-participant factors stimulus type and response) were excluded from the analyses (1.532% of the trials). The four goal commitment items (Cronbach's alpha = .686) were combined to form a mean goal commitment score for each participant, and an independent samples t test confirmed that goal commitment did not differ between the arm movement (M = 4.755, SD = 1.157) and the no-arm movement (M = 4.856, SD = 1.063) conditions, $t < 1$, ns.

Results

Main analysis: Stimulus type by response interaction. We ran the linear mixed model analysis from Study 1 with the addition of the between participant factor Movement and the resulting additional interactions. The analysis showed the expected stimulus type by response interaction effect, $\chi^2(1) = 12.418$, $p < .001$, $\Omega_0^2 = .347$, and as predicted, no three-way interaction effect of these factors with the movement condition, $\chi^2(1) = 0.065$, $p = .799$, ns (see Figure 3a). The same mixed-model analysis performed on the response errors showed a significant stimulus type by response interaction effect, $\chi^2(1) = 8.636$, $p < .01$, raising the concern of a speed–accuracy trade-off (Figure 3a). We again performed an additional analysis on the response times including only participants who made an equal number of errors on critical-pull and critical-push responses (61 out of 94 participants; 65%). This analysis confirms our initial results by showing a similar marginally significant stimulus type by response interaction effect, $\chi^2(1) = 2.926$, $p = .087$, $\Omega_0^2 = 0.386$ (Figure 3b), which was again not qualified by the movement factor, $\chi^2(1) = 0.501$, $p = .479$. Within this subset for whom we can rule out a speed–accuracy trade-off, individual comparisons showed that critical-pull responses (M = 665.626 ms, SD = 100.830 ms) were significantly faster compared to all other conditions; critical-push (M = 678.559 ms, SD = 87.861 ms), neutral-pull (M = 677.944 ms, SD = 83.507 ms), and neutral-push (M = 682.519 ms, SD = 78.317 ms), all p's < .046. This response time pattern mirrors the pattern found for all participants (see supplementary analyses).

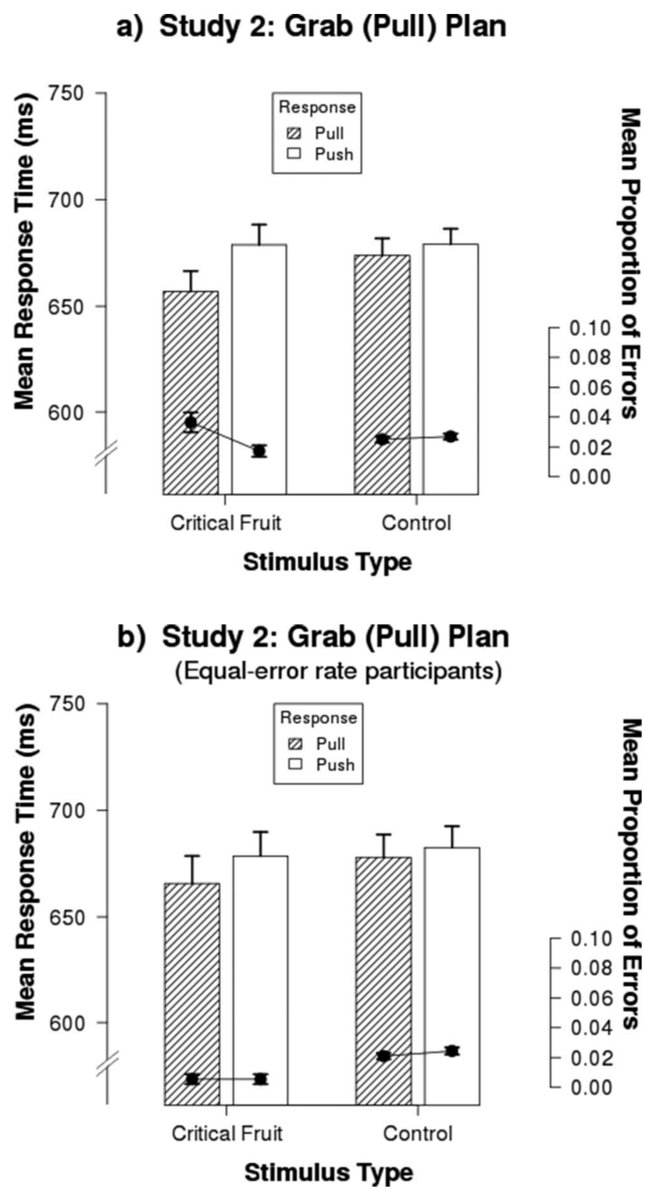

Figure 3. Mean response times (+SEM) and mean error rates per stimulus type and response condition. Figure 3a displays the results for all participants and Figure 3b the results for the majority of participants (65%) having an equal error rate for push and pull responses for the critical fruit stimuli.

Inclusion of fruit liking ratings. A two sample t test confirmed that critical fruit evaluations did not differ between the arm movement (M = 6.298, SD = 1.081) and the no arm movement (M = 6.340, SD = 0.788) conditions, $t < 1$, ns. We then ran another linear mixed effects analysis and added the evaluation of critical fruit stimuli. This analysis confirmed the results reported before: We found a significant stimulus type by response interaction effect, $\chi^2(1) = 12.418$, $p < .001$, and no significant higher order effects. Apparently, evaluations of the critical fruit did not add to the explanatory power of the model and thus liking ratings of the critical fruit can most likely not account for the facilitation of pull responses toward critical stimuli. This provides further evidence in favor of the conclusion that the pull facilitation is a consequence of the respective action planning.

Thus, Study 2 provides additional evidence that planning to grab a particular (edible) object facilitated elbow flexion movements upon perceiving the object. Furthermore, whereas this effect was not moderated by whether participants performed elbow flexion and extension movements during planning or if these movements were inhibited, the generally weaker evidence in Study 2 (i.e., tendency for a speed–accuracy trade-off and a marginally significant effect for those 65% of the participants for which we can exclude a speed-accuracy effect) may have been a result of the additional load created by performing specific physical actions during the planning phase.

Study 3: Turning the Effect Around

To rule out alternative explanations as to why pulling an object toward oneself is facilitated following an if–then action plan to grab a certain fruit, other than our hypothesis that perceptual and motor simulations are bound together during planning, in Study 3, we altered the behavioral components associated with participants' planned action. We expected that the action of "pointing at a fruit" elicits a motor simulation that includes an elbow extension (push) movement as a salient motor component that would become linked to the critical cue. Thus, after having observed a *pull*-response facilitation in Studies 1 and 2, we predicted a *push*-response facilitation for the critical fruit in the point-plan condition of Study 3—a facilitation in the condition that was one of the slowest in the two previous studies. Additionally, we added a control condition in which participants completed the full procedure of choosing a fruit and committing to eating more of that type of fruit, but did not form an if–then action plan. As we propose that the simulation associated with the action plan is the critical part of the procedure, we did not predict an effect in this no-plan control condition. In sum, in Study 3, all participants again set themselves the goal of eating more of a particular type of fruit. However, only participants in the point-plan condition formulated the if–then action plan "If I see a(n) [critical fruit], then I will *point at* it immediately." The remaining participants skipped this plan formation and finally all participants completed the push-pull categorization task.

Method

Participants and design. One-hundred and five students and employees (77 female/28 male) of a German university were randomly assigned to one of the two between-participants conditions of the study. Their mean age was 21.647 ($SD = 6.308$) with a range from 17 to 67. The design followed a 2 (Plan, between: no plan vs. point plan) $\times$ 2 (Stimulus Type, within: critical fruit vs. control) $\times$ 2 (Response, within: push vs. pull) model design with joystick response times in the push-pull categorization task as dependent variable.

Procedure. The study followed the same procedure as Study 1 with the following modifications: Instead of planning to grab the critical fruit, participants received either no action plan (no-plan control condition) or they received a plan to point at the critical fruit (point-plan condition). Thus, in the no-plan control condition, participants received information about setting the goal to eat more healthy food, and also chose the critical fruit they wanted to eat more often. The only difference was that the goal (i.e., "I want to eat more [critical fruit]") was presented alone, without an accompanying action plan. In the point-plan condition, the only difference from Study 1 was that the grab plan was replaced with a point plan ("If I see a(n) [critical fruit], then I will point at it immediately"). Thus, in the entire 10-min procedure of goal setting and action planning, the only difference to Study 1 was that the word "grab" was replaced with the words "point at."

In the test phase, participants completed the same push-pull categorization task as in Studies 1 and 2. In two blocks of 144 trials each, participants categorized stimulus pictures including the critical fruit as belonging to the category of fruit or vegetables by pushing or pulling a joystick.

Data treatment. We treated the data in the same way as in Studies 1 and 2. We excluded three participants from further analyses who reported that they were left-handed but operated the joystick with their right hand, and one participant who was right-handed but operated the joystick with the left hand. The remaining 98 right-handed and 3 left-handed participants operated the joystick with their dominant hand. Furthermore, two participants were identified as outliers (Tukey, 1977) on the push-pull categorization task with error rates of 7.292% and 7.986% as compared with the total samples mean error rate of 2.410% ($SD = 1.748\%$), and were therefore excluded from the analyses. With regard to individual trials, all trials with an erroneous response (i.e., incorrect categorization or failure to respond within 5,000 ms) were excluded from the analyses (2.304% of the trials). Furthermore, trials with response times lower than 200 ms and response times exceeding mean response time plus three times the standard deviation (calculated separately for each participant and the within-participant factors stimulus type and response) were excluded from the analyses (1.511% of the trials). We combined the four goal commitment items (Cronbach's alpha of 0.584) to form a mean goal commitment score for each participant, and a two sample t test confirmed that goal commitment did not differ between the no-plan ($M = 5.081$, $SD = 0.859$) and the point-plan ($M = 4.880$, $SD = 0.961$) conditions, $t(97) = 1.100$, $p = .274$.

Results

We performed the linear mixed effect model analysis from Study 2, replacing the between-participants movement condition with the plan condition (point plan vs. no plan). As expected, the analysis showed a significant three-way interaction effect between plan, stimulus type, and response, $\chi^2(1) = 8.849$, $p = .003$, $\Omega_0^2 = .363$. The same mixed-model analysis performed on the response errors showed *no* significant plan by stimulus type by response interaction effect, $\chi^2(1) = 1.332$, $p = .248$, and thus no evidence of a speed–accuracy trade-off in the error pattern depicted in Figures 4a and 4b. We therefore explored the three-way interaction effect further by analyzing the plan conditions separately.

No-plan control condition. As predicted, the stimulus type by response interaction effect observed in Studies 1 and 2 following a grab plan was not found in this no-plan control condition, $\chi^2(1) = 2.544$, $p = .111$, $\Omega_0^2 = .361$ (Figure 4a). The same analysis with a more liberal specification of the random effects (i.e., only random intercept for participant) also did not result in a significant stimulus type by response interaction effect, $\chi^2(1) = 2.570$, $p =$

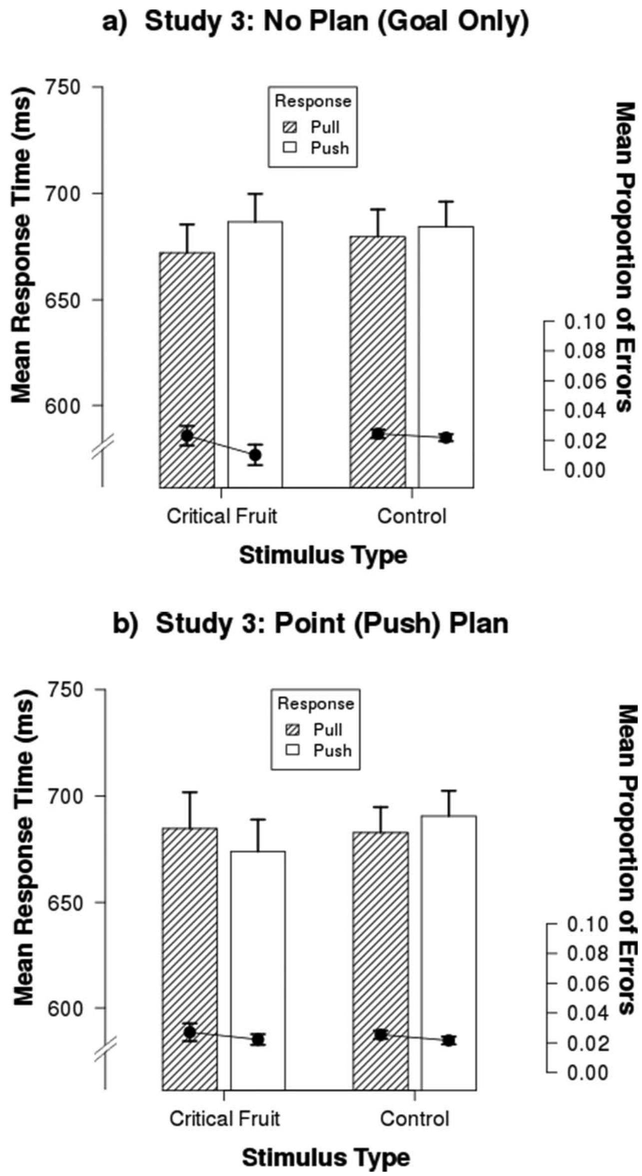

Figure 4. Mean response times (+*SEM*) and mean error rates per plan, stimulus type, and response condition for the full set of participants.

.109. Thus, we can conclude that merely choosing and holding a goal to eat more of a certain fruit—without formulating a plan—does not facilitate any specific movement in response to the critical stimuli.

Point-plan condition. The critical analysis for our main hypothesis rests in the point-plan condition. Assuming that the same mechanisms that led to a facilitation of critical-pull responses in Studies 1 and 2 went into gear in Study 3, we expected to observe an effect in the *opposite* direction (i.e., critical-push facilitation). The same analysis as performed for the no-plan control condition revealed a significant stimulus type by response interaction effect, $\chi^2(1) = 6.972$, $p = .008$, $\Omega_0^2 = .368$, for the point-plan condition (Figure 4b). This indicates that the difference between push and pull response times was different for the critical stimuli compared with the neutral stimuli. For neutral stimuli, we again found the baseline effect revealed in the previous studies (see supplemental material); neutral-pull responses (M = 682.789, SD = 84.814) were significantly faster than neutral-push responses (M = 690.568, SD = 84.028; $p < .001$). This baseline effect in combination with the significant two-way interaction effect indicates that the baseline effect is reversed for the critical stimuli so that, descriptively, critical-push responses (M = 673.879 ms, SD = 106.383) are faster compared with pull responses to critical stimuli (M = 684.699 ms, SD = 120.680 ms; p = .601) and neutral stimuli (M = 682.789 ms, SD = 84.814 ms; p = .854). Analyzing the only individual comparison not affected by the baseline response time differences between push and pull responses, we found that critical-push responses (M = 673.879 ms, SD = 106.383) were significantly faster than neutral-push responses (M = 690.568 ms, SD = 84.028, p = .026), demonstrating that the point plan facilitated the pushing response to the critical stimuli only.

In sum, removing the if–then plan from the goal setting procedure eliminated the differences in the response time pattern for the critical fruit compared with the control stimuli; only the baseline bias for generally faster pull responses compared to push responses was found (see supplemental analyses). However, as the dichotomous (marginally) significant criterion was missed only slightly, we cannot unequivocally interpret this as a null effect. The more important and clear conclusion can be drawn from the point-plan condition and the evidence that the response pattern of the point-plan condition is different from the no-plan condition. After finding evidence for facilitated pull responses after planning to grab the critical object in Studies 1 and 2, in Study 3 this effect was reversed after planning to point at the critical object (i.e., relative facilitation of critical-push responses)—an action that when simulated should involve an elbow extension (push) movement.

Study 4: Directly Comparing the Grab and Pull Plan

Study 4 was designed to replicate the critical-push facilitation effect following a point plan found in Study 3 and statistically compare it to a third test of the critical-pull facilitation effect following a grab plan.

Method

Participants and design. One-hundred students and employees (54 female/46 male) of a German university were randomly assigned to one of the two between-participants conditions of the study. Their mean age was 22.390 (SD = 4.731) with a range from 18 to 57. The design followed a 2 (Plan, between: grab plan vs. point plan) × 2 (Stimulus Type, within: critical fruit vs. control) × 2 (Response, within: push vs. pull) model design with the joystick response times in the push-pull categorization task as the dependent variable.

Procedure. The procedure of the grab-plan condition followed the procedure of Study 1, and the procedure of the point-plan condition followed the procedure of the point plan condition in Study 3. Thus, the only difference between the two conditions in this fourth study were the words “grab” versus “point at” in the action plan “If I see a(n) [critical fruit], then I will grab/point at it immediately.” Again, in the test phase, participants completed the same push-pull categorization task as in Studies 1, 2, and 3 with two blocks of 144 trials of the push-pull categorization task.

Data treatment. We treated the data in the same way as in Studies 1, 2, and 3. We excluded four participants from further analyses who were left-handed but operated the joystick with their right hand, and one participant who was right-handed but operated the joystick with the left hand. The remaining 93 right-handed and 2 left-handed participants operated the joystick with their respective dominant hand. Furthermore, four participants were identified as outliers (Tukey, 1977) on the push-pull categorization task with error rates of 7.986%, 7.986%, 8.681%, and 10.416% as compared with the total sample's mean error rate of 2.311% (SD = 2.064%), and were therefore excluded from the analyses. Finally, we excluded eight participants who indicated in a binary choice question in the final questionnaire that they had previously participated in a similar study. This question was added to the fourth study to ensure we did not inadvertently include participants from the earlier studies.

As in past studies, all trials with an erroneous response (i.e., incorrect categorization or failure to respond within 5,000 ms) were excluded from the analyses (2.000% of the trials). Furthermore, trials with response times lower than 200 ms and response times exceeding the mean response time plus three times the standard deviation (calculated separately for each participant and the within-participant factors stimulus type and response) were excluded from the analyses (1.733% of the trials). We combined the four goal commitment items (Cronbach's alpha = .650) to form a mean goal commitment score for each participant, and a two sample t test confirmed that goal commitment did not differ between the grab plan ($M = 4.594$, $SD = 1.043$) and the point plan ($M = 4.390$, $SD = 1.240$) conditions, $t(80.225) < 1$, ns.

Results

We performed the linear mixed effect model analysis from the previous studies and found the predicted significant three-way interaction effect between plan, stimulus type, and response, $\chi^2(1) = 6.158$, $p = .013$, $\Omega_0^2 = .250$ (see Figures 5a and 5c). The same mixed-model analysis performed on the response errors showed a significant plan by stimulus type by response interaction

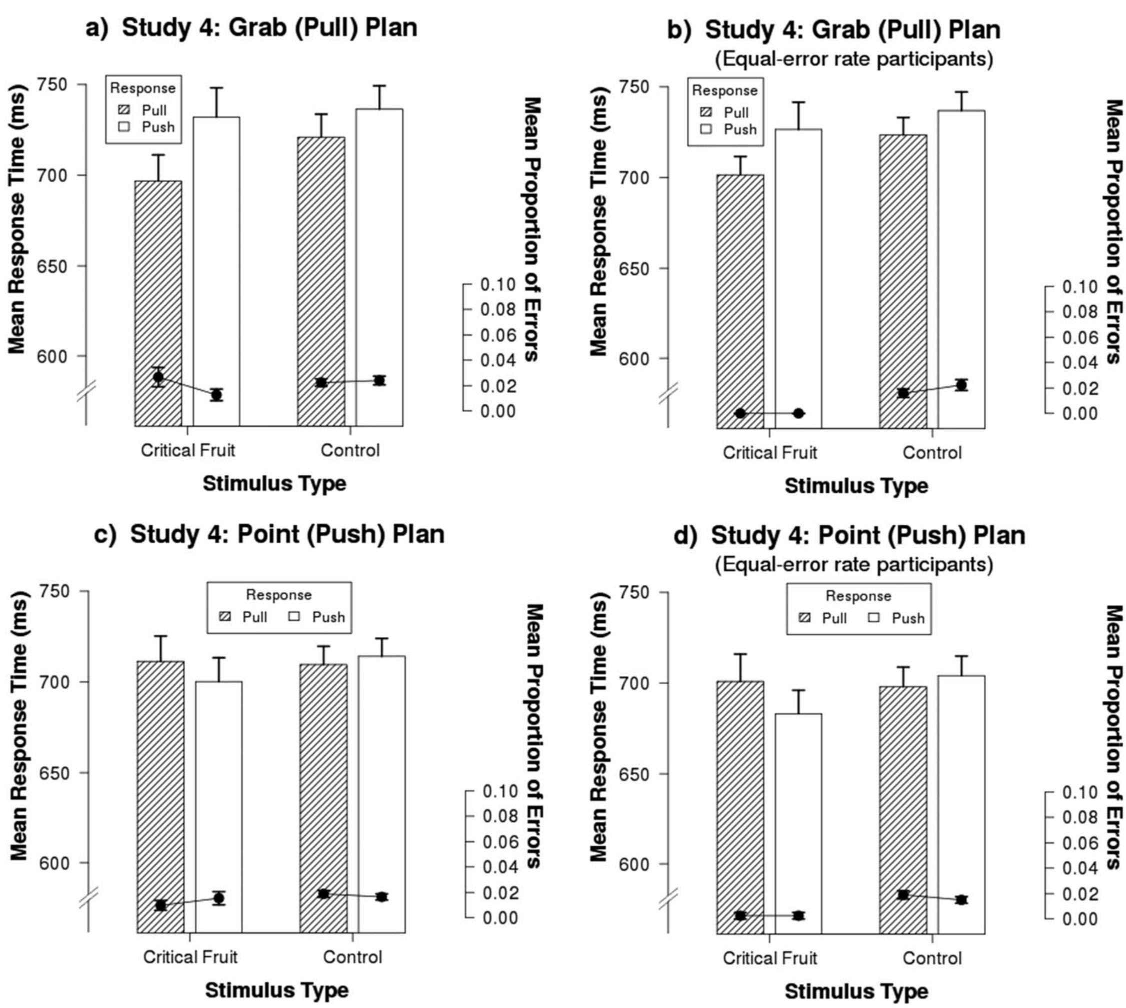

Figure 5. Mean response times (+SEM) and mean error rates per plan, stimulus type and response condition. Figures 5a and 5c displays the results for all participants and Figures 5b and 5d for the participants (71%) with an equal error rate for push and pull responses for the critical fruit stimuli.

effect, $\chi^2(1) = 3.936$, $p = .047$, and an error pattern displayed in Figures 5a and 5c that raises the concern of a speed–accuracy trade-off.

As in Studies 1 and 2, we performed an additional analysis on the response times including only the participants who made an equal number of errors on critical-pull and critical-push responses (59 out of 83 participants; 71%) to rule out this speed–accuracy trade-off explanation. Our analysis replicated the above pattern with a significant plan by stimulus type by response interaction effect, $\chi^2(1) = 5.666$, $p = .017$, $\Omega_0^2 = .207$ (Figures 5b and 5d). The subsequent separate analyses for each plan condition included only this subset of participants. We did not observe a stimulus type by response interaction effect for the grab-plan condition, $\chi^2(1) = 0.792$, $p = .374$, $\Omega_0^2 = .160$ (26 participants, Figure 5b), but observed the predicted stimulus type by response interaction effect for the point-plan condition, $\chi^2(1) = 6.620$, $p = .010$, $\Omega_0^2 = .222$ (33 participants, Figure 5d).

Although the interaction for the plan to grab a particular fruit did not reach a significant level in this third test, the response-time pattern in the current study was similar to Studies 1 and 2. The critical-pull responses ($M = 701$ ms, $SD = 52$ ms) were faster than the mean responses in all other conditions; critical-push ($M = 726$ ms, $SD = 77$ ms), neutral-pull ($M = 723$ ms, $SD = 50$ ms), and neutral-push ($M = 737$ ms, $SD = 52$ ms; all $ps < = .089$). The responses following the plan to point at a particular fruit provided a clear replication of the respective condition from Study 3. As in Study 3, the most important individual comparison—the one not affected by the baseline bias for generally faster pull responses—shows that the critical-push responses ($M = 683$ ms; $SD = 74$ ms) were significantly faster than the neutral-push responses ($M = 704$ ms; $SD = 62$ ms; $p = .017$). Thus, the significant three-way interaction effect along with the pattern of results for the individual plan conditions provide a basic replication of the results found in Studies 1, 2, and 3, with the addition of a direct comparison of the two plans.

General Discussion

In the present research, we explicate a theoretical framework for how language-based action planning translates into actual stimulus-induced behavior, and we provide empirical evidence for this simulation account of action planning. Our theoretical framework rests on three rather straightforward assumptions: (a) Based on modern simulation theories of cognition (e.g., Barsalou, 1999), we expect that verbally processing an if–then action plan activates respective sensorimotor simulations of the content in perceptual and motor brain areas. (b) The temporal overlap of these activity patterns should result in their integration (Hebb, 1949), and thus (c) the later activation of the perceptual activity pattern upon perceiving the actual situation should increase the likelihood of coactivating the integrated motor activity pattern by means of spreading activation. The simplicity of this framework and the fact that no translation processes are needed from a higher level cognition (e.g., thought) to the low-level cognition (e.g., perceptual and motor processes) is a consequence of basing the framework on modern, grounded cognition theories in which thought is based on activity in perceptual and motor brain areas (e.g., Barsalou, 1999). Thus, the presented model provides an explanation of how an agent's conscious thought induces actual actions, and how mere thought can create direct stimulus-response links.

The Empirical Evidence

In four studies, we accumulated evidence of how systematically manipulating participants' thoughts during action planning causes subsequent reductions in latencies to initiate plan-compatible actions. We interpret the response facilitation as evidence for the activation of a specific motor component of the planned action, triggered by the perceptual activation of the critical cue. More specifically, whenever participants planned to *grab* a certain fruit—an action involving moving something edible toward the self, represented by elbow flexion motor activity—we found elbow flexion movements to be facilitated upon perceiving that specific kind of fruit in a subsequent, unrelated task. In turn, whenever participants planned to *point at* a certain fruit—an action we expected to be represented by elbow extension motor activity—we found elbow extension movements to be facilitated upon perceiving that specific kind of fruit in the subsequent, unrelated task. Importantly, as it is the key characteristic supporting our simulation account, the verbal content of the action plans did not include explicit references to elbow flexion or elbow extension movements (e.g., words like "pull," "push," "closer," "away," "extend," or "flex"); we expected these motor components would be activated through a simulation of the planned behavior. This behavioral-method approach has clear limitations. Most importantly, we do not provide direct evidence for actual perceptual and motor stimulations during the planning phase. Instead, we base this hypothesis on the accumulated evidence provided by research on simulation accounts of cognition and language comprehension (e.g., Barsalou, 1999, 2010; Kiefer & Pulvermüller, 2012) and there remains a general demand for future research to consolidate this evidence.

We observed a speed–accuracy trade-off in Studies 2 and 4, and addressed this potential problem by analyzing the subset of participants for whom we could definitely exclude the possibility of a speed–accuracy trade-off. Analyzing the response times of those participants who made an equal number of response errors for push and pull responses to critical fruits (~95% of them made no errors at all in these trials) included the majority of our samples (65%–71%) and validated the predicted pattern of response latencies obtained with the full sample. The reason we observed a speed–accuracy trade-off may lie in the wording of the intended action, which included a reference to responding quickly (i.e., "Then I will point at it *immediately*"). Thus, the characteristic of being fast may have additionally become associated with the critical fruit and thereby contributed to induce fast responses which, for a minority of the participants, resulted in a higher error rate.

If–Then Planned Behavioral Automaticity?

Past researchers have attempted to address the question of whether action initiation following an if–then action plan is truly automatic, and strong evidence in favor of the automaticity claim has been provided (e.g., *fast*, Cohen et al., 2008; and *minimal cognitive resources needed*, Brandstätter et al., 2001; summarized by Gollwitzer, 2014). However, the possibility remains that the effects of planning on behavior are consciously mediated—especially as most of the prior research investigated action planning with a rather direct contingency between the planned action and the subsequently assessed behavior (e.g., planning to press the left button and assessing left button presses). Our current studies extend this prior evidence in important ways, through a less obvious relationship between the planned action (e.g., to point at an apple) and the assessed responses in the push-pull categorization task (e.g., pushing the joystick to categorize food items). Even though other research with a less direct correspondence between the intended action and the assessed behavior has been conducted, this research only examined the readiness to perceive the critical situation (Wieber & Sassenberg, 2006). In the present research, in contrast, the planning effect can unequivocally be attributed to the behavioral response component of if–then action planning, as the effect was reversed through changing the planned action in Studies 3 and 4.

In line with prior research showing that even a nonconscious presentation of a situational cue can activate the associated behavior (Bayer et al., 2009), we provide evidence that if–then action planning creates a direct perception-action link between the critical situation and the intended action. Still, the current research goes beyond providing evidence for the automaticity claim of if–then planned action initiation: We provide a theoretical framework for *how* conscious thought in the form of action planning creates such links to influence subsequent actions.

Motor Simulation Versus Action-Effect Principle

It has been repeatedly proposed and demonstrated that representations of an action's effects can activate the actions required to produce the effect (*ideo-motor principle* or *action-effect principle*, Elsner & Hommel, 2001; James, 1890; Prinz, 1997). In our case, this would mean that a perceptual simulation of the action outcome (e.g., having the apple at one's mouth or observing one's extended arm pointing at something) could have activated the required motor actions to produce this outcome. This possibility dovetails with our simulation account that highlights the role of simulation in perceptual and motor areas as the basis of higher cognitive functions like thought. So the question arises: To what degree is the intended action represented by low-level activity in motor brain areas representing the intended action or by low-level activity in perceptual brain areas representing the action effect? The degree of this contribution may be a function of how abstract the intended action is; a very simple action may receive more of a contribution from actual motor components whereas a very abstract action may be driven purely by the outcome and action-effect principles. In sum, as there is evidence for language-specific effects in motor brain areas, we think it is likely that both motor simulations of the intended actions and perceptual outcome simulations contribute to the observed behavior.

Implications for Understanding the Control-Automaticity Dimension

Our notion of self-instructed automaticity has consequences for the interpretation of experimental results in different areas. For example, a recent study has been interpreted as evidence for *free will* (Schultze-Kraft et al., 2016). The authors adapted a paradigm from studies questioning free will that had shown "free" decisions were preceded by subconsciously building brain activity (readiness potential) preparing the decision before it was made (Haggard & Eimer, 1999; Soon et al., 2013). In this study, the authors (Schultze-Kraft et al., 2016) harnessed the building readiness potential to turn on a stop signal whenever the readiness potential indicated the preparation of a response. Participants were instructed to stop executing the action whenever the stop signal appeared. Despite the subconscious preparation of the action, upon perceiving the stop signal, the participants were able to intervene and stop their responses. The authors interpreted this as a "free" veto with which participants were able to control their actions freely. This interpretation, however, rests on the assumption that an instructed stimulus-response binding (e.g., if you see the stop signal, then stop your action) is voluntarily and "freely" executed. From our perspective, the instructions prior to the task induced a kind of if–then action plan. Instead of a voluntary veto interrupting the subconscious action preparation, in situ, two subconscious processes were interacting with one another: The readiness potential preparing the action and the stimulus-induced inaction. Our interpretation would thus be that in situ actions are determined by subconsciously prepared brain activity outside of one's voluntary control. However, this brain activity can be strategically manipulated prior to critical situations by appropriate action planning. Thereby, even without in situ control, upon entering the situation, one has already modified the odds into the direction of one's will.

In a similar vein, there are various practical research areas, for example on affect, stereotypes, and habitual behavior, in which automatic processes undermine conscious intentions. However, empirical evidence is emerging that if–then planning can be used to control affect (Gallo, Keil, McCulloch, Rockstroh, & Gollwitzer, 2009), automatic stereotypes (Stewart & Payne, 2008), and reflexive responses (Cohen et al., 2008; Miles & Proctor, 2008). From the theoretical perspective presented in the current research, it is no surprise that such automatic processes can be influenced by prior thought—thought in an if–then format. Our theoretical framework provides an explanation of how this is achieved.

Contributions and Limitations of the Presented Research

The main theoretical contribution of the current paper is a new framework to describe the mechanisms by which verbal, conscious thought might influence subsequent actions. With the proposed framework we demonstrate how using simulation accounts of cognition can provide a parsimonious explanation (cf. Occam's razor) for the causal effect of verbal action plans on subsequent actions. Empirically, we provide evidence that verbal, conscious thought is causally related to subsequent actions—a conclusion that may seem trivial from a subjective perspective (e.g., Haggard & Chambon, 2012) but is not at all trivial from a scientific perspective (Haggard & Eimer, 1999; Libet et al., 1983; Soon et al., 2013). We used a disconfirmatory strategy to test this conclusion by reversing our experimental manipulation, repeatedly finding the predicted reversed outcome. However, our current empirical approach is clearly limited in its ability to provide evidence for simulation accounts of cognition directly, and more specifically, in providing evidence that actual modal simulations were enacted during the planning phase in our studies. We do not test this assumption directly—we only have indirect evidence that is in line with simulation accounts. The investigated responses are based on movements that were not included in the verbal reference of the response (i.e., "point at an apple" and elbow extension) but which we expected to be included in a simulation of the action. Moving one's arm, hand, and pointing finger into a position to point at something in the environment most likely includes an elbow extension.

Besides this reasoning, we base our assumptions regarding motor simulations on earlier research. Not surprisingly, with such a paradigm-shifting proposal as the idea behind simulation accounts of cognition, there are strong proponents (e.g., Glenberg, 1999) and opponents (e.g., Goldinger, Papesh, Barnhart, Hansen, & Hout, 2016); there is confirmatory evidence of specific aspects (Schaller, Weiss, & Müller, 2017), alternative interpretations of evidence (Firestone & Scholl, 2016), disconfirmatory evidence (Rommers, Meyer, & Huettig, 2013), and replication failures of confirmatory evidence (Papesh, 2015). This ambiguity surrounding many aspects of the embodied cognition approach therefore demands a clear statement of what conclusions we can confidently draw from our studies and what remains to be further investigated. In this regard, we suggest there is a need for further studies with manipulations that directly interfere with (Beilock & Holt, 2007) or facilitate (Thomas & Lleras, 2009) potential motor-area simulations in order to test the hypothesis that such simulations are present and causally involved in the effects of action planning.

Conclusion

In the present work, we provide evidence that manipulating minimal but semantically important aspects in an agent's action planning (i.e., thought) influences subsequent actions in a rather automatic fashion. Thus, conscious thought—formulating an if–then action plan—creates direct perception-action links and thus enables behavioral automaticity. We propose that the process of how this is done is a consequence of the cognitive architecture in which actual perception and action, and thought about perception and action, are based on the same brain structures. Our framework may feel quite behavioristic as it suggests that in situ actions are largely environmentally triggered. However, instead of depending only on habitual stimulus–response associations, the associations we consider in the present paper had their origin in if–then action planning (i.e., conscious thought).

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