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Attentional control and inferences of agency: Working memory load differentially modulates goal-based and prime-based agency experiences

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A R T I C L E   I N F O

A B S T R A C T

Previous research indicates that people can infer self-agency, the experience of causing outcomes as a result of one's own actions, in situations where information about action-outcomes is pre-activated through goal-setting or priming. We argue that goal-based agency inferences rely on attentional control that processes information about matches and mismatches between intended and actual outcomes. Prime-based inferences follow an automatic cognitive accessibility process that relies on matches between primed and actual information about outcomes. We tested an improved task for a better examination of goal-based vs. primed-based agency inferences, and examined the moderating effect of working memory load on both types of inferences. Findings of four studies showed that goal-based, but not prime-based agency inferences dwindled under working memory load. These findings suggest that goal-based (vs. primed-based) agency inferences indeed rely on attentional control, thus rendering goal-based agency inferences especially prone to conditions that modulate goal-directed control processes.

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1. Introduction

The sense of agency – the feeling that one causes one's own actions and their subsequent outcomes – is a pervasive and fundamental aspect of human self-perception and social functioning. The sense of agency has been explained in two separate, but complementary models. Initially, self-agency has been studied as a product of comparator processes described in models of motor control (Frith, Blakemore, & Wolpert, 2000; Wolpert & Flanagan, 2001). The execution of a goal-directed action is accompanied by the prediction of sensory action-outcomes based on internal copies of movement-predicting signals (i.e., efference copies) generated by the sensorimotor system. These internal motor predictions are generally short-lived but very reliable, and sensory outcomes are readily perceived as self-produced until this prediction no longer corresponds with the actual outcomes. However, some situations are too ambiguous for motor predictions to be reliable. Interestingly, people still experience self-agency in these situations, for example when there is no causal link between action and following event (Moore & Haggard, 2008), when people move involuntarily (Dogge, Schaap, Custers, Wegner, & Aarts, 2012; Moore, Lagnado, Deal, & Haggard, 2009) or when actions have multiple causes and outcomes (Van der Weiden, Ruys, & Aarts,

2013; Wegner, 2002). This recent work points to an additional – non-motor prediction – process of agency experiences. This so-called inference account of agency suggests that when motor signals are absent or unreliable, agency can still be established when there is a match between the actual outcome and pre-activated information that is related to the outcome (Aarts, Custers, & Wegner, 2005; Wegner & Wheatley, 1999).

Whereas the motor-prediction process of agency has received much theoretical and empirical attention (see Hughes, Desantis, & Waszak, 2013), research on the mechanism underlying agency inferences has been relatively limited. The present research aims to further the understanding of agency inferences by examining how two distinctive sources of information shape the experience of self-agency (Aarts et al., 2005; Van der Weiden et al., 2013). Firstly, the experience of self-agency can emerge from *goal-based* inferences, which is the case in situations where people engage in goal-oriented behavior and their attention is directed toward subsequent outcomes they intend to attain. Additionally, other situations can give rise to *prime-based* self-agency inferences, for example when people engage in actions that are more spontaneous and prepared without much attention, and observe outcomes that are in line with information that is merely pre-activated in mind. Both types of agency inferences can occur independent of motor predictions, and contribute to a sense of selfhood, feeling of control and social behavior during daily social interaction (Frith, 2013). Despite the importance of both types (goals and primes) of agency inferences for human functioning, little is known, however, about whether and how goal and prime-based inferences differ in shaping self-agency experiences. Here, we report a set of studies that (a) tested an agency inference task that allows for a clear examination of goal-based vs. primed-based agency inferences, and (b) explored whether the occurrence of goal-based agency inferences vs. primed-based agency inferences differ as a function of attentional control processes that are installed by goal-directed thought and action.

As alluded to above, research on agency inferences distinguishes two routes to the experience of agency that are based on the pre-activation of outcome information. Based on whether actual outcomes match or mismatch with the mental preview of the outcome, self-agency is inferred. In daily life this is often experienced as a result of our explicitly set goals as part of intentional behavior. That is, if one had the goal of bringing about a specific outcome and that outcome actually occurred, one must have caused it. If there is a mismatch, one may infer that one was not the cause. However, recent findings suggest that self-agency experiences can also arise from a more implicit source of information. Specifically, observing action-outcomes that were previously primed also provides the feeling we caused the outcome to occur. This implicit route pertains to agency inferences that can result from instances in which the source of the experience of agency is likely to remain outside of awareness, as is, for example, often the case during social interactions. Both goal-setting and mere priming have been found to contribute to agency inferences across various tasks (e.g., Aarts et al., 2005; Linser & Goschke, 2007; Sato, 2009; Van der Weiden, Aarts, & Ruys, 2011; Van der Weiden et al., 2013; Wegner & Wheatley, 1999), suggesting that agency experiences result from a cognitive process that relies on agency-relevant outcome information, irrespective of whether this information is pre-activated by goal-setting or priming.

However, recent research suggests that goals and outcome-primes impact self-agency experiences differently. Specifically, whereas explicitly set goals to produce an action-outcome and implicit priming of the action-outcome both increase agency experiences when the actual outcome matches the pre-activated outcome, only goals substantially decrease agency experiences when outcomes mismatch the goal. This finding has been taken to suggest that the underlying mechanism of goal-based agency inferences and prime-based agency inferences differ (Van der Weiden et al., 2013). Building on the proposed distinctive effects of goal-setting and mere priming on information processing and behavior (Aarts, 2012; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Fishbach & Ferguson, 2007), goal-based effects on agency inferences are considered to involve attentional control in which the person attends to specific outcomes she wants to obtain. However, outcome-priming effects on agency inferences are proposed to rely on a more automatic cognitive accessibility process that follows principles of spreading of activation and, in principle, does not heavily engage attentional control processes (Van der Weiden et al., 2013). Accordingly, goal-setting (but not outcome-priming) causes individuals to focus attention on the attainment of the intended outcome and to process feedback information and learn from expected (matches) and unexpected (mismatches) results (Baddeley, 2007; Carver & Scheier, 1998; Conway et al., 2005; Custers & Aarts, 2007; Frith et al., 2000).

If this notion about the difference between goal-based and prime-based agency inferences is correct, then taxing attentional control (i.e., by working-memory load) should differentially affect these inferences. Increasing working-memory load has been demonstrated to diminish the ability to freely focus attention on secondary tasks and process feedback information, showing impaired performance in goal attainment (e.g., Baddeley, 1986; Baddeley, 2007; Hester & Garavan, 2005; Lavie, 2010; Lavie, Hirst, de Fockert, & Viding, 2004; Ward & Mann, 2000). Accordingly, taxing attentional control should deteriorate goal-based, but not prime-based agency inferences, as outcome-priming effects are suggested to not heavily rely on attentional control. There is some preliminary evidence supporting this notion (Hon, Poh, & Soon, 2013). Hon et al. (2013) asked their participants to set goals to produce an outcome in an action-outcome dependency task (pressing an up and down arrow to move a dot in the direction consistent or not with the arrow) and required them to maintain either two or six consonants in memory while performing the task. Results showed that a higher working-memory load (i.e., remembering six consonants) caused decreased experiences of agency of matching (but not mismatching) outcomes. Although these findings suggest that working-memory load affects experiences of agency, this study is unclear in delineating motor prediction from cognitive inferences. Moreover, participants only set goals and were not primed with outcome information. Accordingly, this study does not directly speak to the issue of whether goal-based and prime-based agency inferences differ in the way they materialize.

1.1. The present study

The present study serves two main goals. First, we present two experiments to replicate the differential effects of goal-based and prime-based agency inferences as a function of matching and mismatching outcomes by using a new and improved agency task in which action and outcome are independent. Previous studies (Aarts et al., 2005; Renes, Vermeulen, Kahn, Aarts, & van Haren, 2013; Van der Weiden et al., 2013) addressing this issue have all been employing a specific procedure, one that does allow goal-setting to differ from outcome-priming in terms of preparation before performing an action and observing an outcome. Specifically, in goal trials participants first think about which outcome they aim to attain (for 3 s) and formulate their action-goal accordingly (e.g., pressing a key to stop the rapid alternation of words on a computer screen at a specific word), and then engage in the stimulus alternation task before performing an action (pressing a key) and observing the well-prepared outcome. In the prime trials, participants engage directly in the stimulus alternation task, and are primed with the outcome (e.g., a word) just before they press a key and observe the outcome. In other words, goal-based inferences were tested in a setting where goals could be prepared in an unconstrained way, whereas information is not processed as freely in prime-based inferences. This poses the question whether goals only impact self-agency experiences when processed extensively and without interruption, and whether the way primes are presented might prevent them from impacting self-agency experiences like goals do. Therefore, the present study aims to first demonstrate the robustness of the current ideas by testing a more internally valid task, where information about both goals and primes is presented amidst the alternation of information and at the same moment in time, thereby ensuring a more equal empirical test for the impact of goals and primes on agency inferences.

The second goal of the present study is to employ the new agency inference task to explore whether goal-based agency inferences rely more on attentional control than prime-based inferences do. For this purpose, we examined the occurrence of goal-based and primed-based agency inference under different levels of working memory load. If goal-based agency inferences indeed rely on attentional control, then the impact of goals on agency experiences should diminish when working memory is taxed. Because primed-based agency inferences are suggested to not engage much attentional control processing, taxing working memory are expected to not (or to a lesser extent) modulate the impact of primes on agency inferences.

1.2. Experiment 1a

In order to test the differential effects of goal-based and prime-based self-agency inferences, we used a task in which participants perform an action (pressing a key) that is followed by an outcome (the color word red or blue presented on the computer screen) that either matches or mismatches the goal or primed outcome. Importantly, goals and primes are presented at a similar time within the same distractive task before performing the action, ensuring participants had equal opportunity to process this information and prepare the action.

2. Methods

2.1. Participants

Experiment 1a included twenty-five right-handed participants (M_{age} = 22.24, SD = 3.24; 15 females). All participants received course credit or a monetary reward in exchange for their participation.

2.1.1. Procedure

The agency inference task was adapted from Van der Weiden et al. (2013, experiment 2). Before starting the experiment, participants were told that the task was designed to assess how experiences of self-agency come and go, and were asked to indicate how these experiences vary during the task. Similar to playing a slot machine, this task required participants to stop a sequence of rapidly presented information to produce a particular outcome (i.e., the color word red or blue) on the computer screen. Specifically, participants pressed a key in response to a cue while viewing alternating letter strings. Upon pressing this key, the stream of letter strings stopped and the color word 'red' or 'blue' was presented. This outcome could either match or mismatch with prior knowledge regarding the action-effect (i.e., goals or outcome primes; see below). In addition, participants learned that the computer could have caused the presented outcome as well. In other words, the cause of the observed effect was ambiguous (Aarts et al., 2005; Sato, 2009). After viewing the effect following their key press, participants reported their feelings of agency over causing the perceived effect.

Each trial consisted of five different phases: an exposure phase, a filler phase, an action phase, an outcome phase and a rating phase (see Fig. 1). The last four phases were identical for all trials. During the filler phase, participants attended to rapidly alternating letter strings. This interval served as a delay between exposure to pre-activated information and the action that was also present in previous work on agency inferences (e.g., Van der Weiden et al., 2013). In the action phase, participants responded to a circle that was presented above or below the letter strings by pressing the corresponding upper or lower key on a response box with their right index finger (required upper and lower key presses were evenly distributed and randomly selected across all experimental trials). The interval in which a response could be given lasted 800 ms. If participants pressed the key within this interval, the strings continued to alternate until the end response interval, whereas if they pressed too late, an error message occurred and the trial was processed as missing.
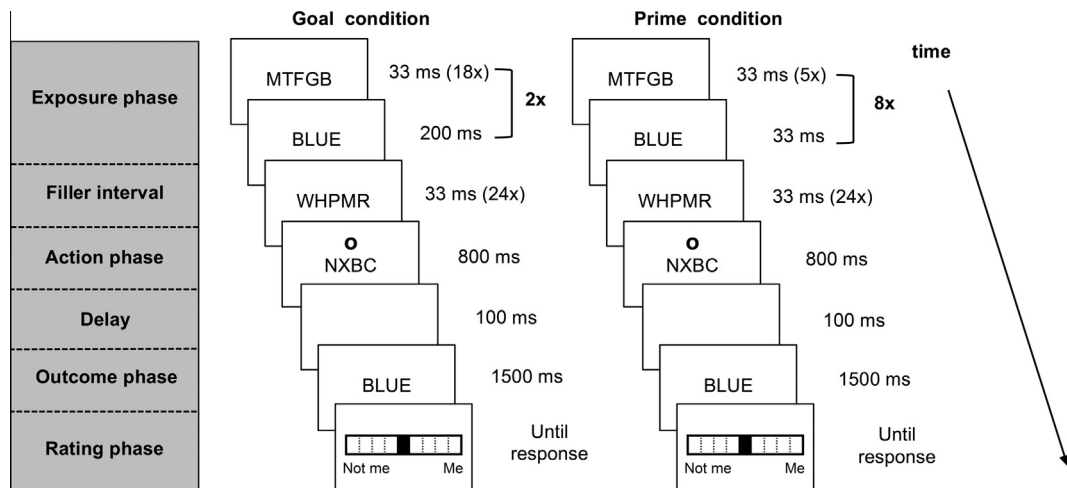
Fig. 1. Schematic presentation of a match trial in the agency inference task for the goal condition and the prime condition. Presentation times are rounded based on a 60 Hz monitor (e.g., 33 ms. equals 2 cycles).

Following the action phase, the color word 'red' or 'blue' (counterbalanced between trials) was shown for 1500 ms. A 100 ms delay was added between the action and outcome phase to make the two phases more distinguishable. To ensure that participants would maintain looking at the letter strings, participants were told that pressing the key during the presentation of a string containing the letter R (e.g., MTFR) would cause the word 'red' to appear, whereas a key press during the presentation of a string containing the letter 'B' (e.g., NXBCZ) was followed by the word 'blue'. Letter strings were presented for 2 cycles on a 60 Hz LCD screen (thus, presentation time was ±33 ms). In reality, the computer determined the presentation of color words. Thus action and outcome were independent, ruling out the potential contribution of motor-prediction cues.

After each trial, experienced agency was assessed during a rating phase by asking participants to what extent they felt their key press caused the presented color word to occur. They could respond by moving a square on an 8-point analogue scale ranging from 'not me' (1) to 'me' (8). The square was positioned in the middle of the scale and participants had to provide their response by moving the square to the left (not me) or the right (me) of the scale.

2.1.2. Pre-activated information about outcomes

As mentioned earlier, the exposure phase was not identical for all trials. Specifically, in this phase information regarding the outcome was activated by either goals or by primes.

In goal trials, participants were exposed to a series of 18 letter strings followed by a color word that was clearly presented on the screen for 200 ms. This sequence was repeated twice, such that participants were two times exposed to the goal within a 1600 ms period (see Fig. 1). Participants were instructed to form the goal to produce the color word that appeared within the series of letter strings.

In outcome prime trials, participants were exposed to a series of 5 letter strings followed by a briefly presented color word (±33 ms). This sequence of events was repeated eight times, resulting in a total of 8 primes within a 1600 ms period (see Fig. 1). Note that the duration of the exposure phase was identical for both types of pre-activation. Importantly, participants were not instructed to formulate a goal in the prime trials.

The goal trials and outcome prime trials were presented in two separated (counterbalanced) blocks which each consisted of 64 randomly presented trials. In half of the trials, pre-activated color words corresponded with the actual outcome, whereas in the other half of the trials they did not correspond with this outcome. Before the critical trials of the first block, participants first practiced (eight trials) both blocks in counterbalanced order. Additionally, the second block was preceded by four practice trials to ensure participants' understanding of the task. In between the two blocks participants were allowed to have a break. Furthermore, participants paused for thirty seconds after completing the first half (i.e., 32 trials) of each block.

2.2. Results

Due to the absence of a key press within the interval of the action phase, 5.7% of the total number of trials were excluded from the analyses. Mean agency experiences were calculated for matches and mismatches in the goal trials and in the prime trials. Averaged self-agency experiences were subjected to a 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs. Mismatch) repeated-measures ANOVA. See Fig. 2 for an overview of the results. The analysis yielded no main effect for Type of pre-activation, $F(1, 24) = 0.43$, $p = .52$, $\eta\rho^2 = .02$, showing equal average self-agency experiences in both the goal and outcome prime trials. As expected, the main effect of Matching was significant, $F(1, 24) = 10.43$, $p = .004$, $\eta\rho^2 = .30$, indicating that when outcome-information matched the actual outcome, more self-agency was

experienced than when it mismatched the actual outcome. Furthermore, a Type of pre-activation by Matching interaction was found, $F(1,24) = 8.91$, $p = .006$, $\eta\rho^2 = .27$. To gain more insight into this interaction, follow-up analyses were performed. In both tasks the main effect of Matching was significant (Goal: $F(1,24) = 10.18$, $p = .004$, $\eta\rho^2 = .30$; Outcome prime: $F(1,24) = 7.38$, $p = .012$, $\eta\rho^2 = .24$), where the difference in effect size between the tasks qualifies the interaction between Type of pre-activation and Matching. Furthermore, order of the type of trials (i.e., a block of goal trials first, or prime trials first) did not influence these patterns (interaction of Type of pre-activation and Matching and Order: $F(1,23) = 1.22$, $p = .281$, $\eta\rho^2 = .05$).

2.3. Discussion

In line with expectations, the data indicate that participants experienced stronger self-agency when outcomes matched pre-activated outcome information as compared to when outcomes mismatched such information. Furthermore, the effect of matching was more pronounced for goal-based than for prime-based agency inferences. Supported by the results of Experiment 1a, we aimed to provide an independent direct replication of these findings in Experiment 1b.

3. Experiment 1b

3.1. Methods

3.1.1. Participants

Based on the effect size of the interaction effect observed in Experiment 1a (Cohen's $d_z = 0.60$), and a power of 0.80 ($\alpha = 0.05$), we calculated that we needed at least 25 participants to replicate the effect. We recruited thirty-two undergraduates to take part in Experiment 1b. One participant did not follow instructions, as this person did not vary on agency ratings across the trials. This participant was therefore excluded from analyses. After the exclusion, 31 participants ($M_{age} = 23.48$, $SD = 3.83$; 16 females) were included in the analyses. All participants received course credit or a monetary reward in exchange for their participation.

3.2. Results

Due to the absence of a key press within the interval of the action phase, 2.5% of the total number of trials were excluded from the analyses. Participants' self-agency experiences were averaged and subjected to a 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs. Mismatch) repeated-measures ANOVA (see Fig. 3). Overall, the analyses yielded very similar results as in the previous experiment. No main effect was found for Type of pre-activation, $F(1,30) = 0.90$, $p = .350$, $\eta\rho^2 = .03$, showing equal average self-agency experiences in both the goal and outcome prime trials. Again, the main effect of Matching was significant, $F(1,30) = 16.05$, $p < .001$, $\eta\rho^2 = .35$, showing stronger self-agency experiences when outcome-information matched the actual outcome than when it mismatched the actual outcome. Additionally, the Type of pre-activation by Matching interaction was found to be significant, $F(1,30) = 14.61$, $p < .001$, $\eta\rho^2 = .33$. The follow-up analyses demonstrated a similar difference in effect size of the (significant) goal and outcome prime effects of Matching (Goal: $F(1,30) = 17.55$, $p < .001$, $\eta\rho^2 = .37$; Outcome prime: $F(1,30) = 5.57$, $p = .025$, $\eta\rho^2 = .16$). Finally, the order of the trials did not influence these patterns (interaction of Type of pre-activation and Matching and Order: $F(1,29) = 1.50$, $p = .230$, $\eta\rho^2 = .05$).

3.3. Combined results of Experiments 1a and 1b

To assess the combined effects across the two studies, averaged self-agency ratings of all 56 participants were subjected to a 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs. Mismatch) by 2 (Experiment: 1a vs. 1b) repeated-measures ANOVA. The analysis yielded no main effects of Experiment, $F(1,54) = 1.72$, $p = .196$, $\eta\rho^2 = .03$, or Type of
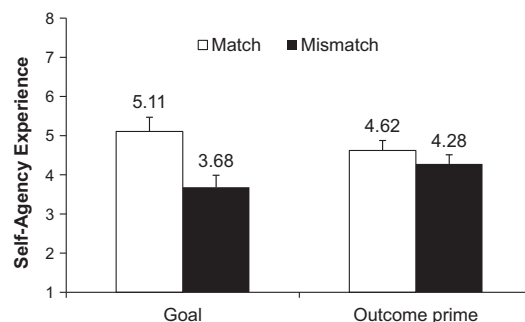

Fig. 2. Self-agency experiences as a function of Type of pre-activation and Matching for experiment 1a. Error bars indicate the standard error of the mean.
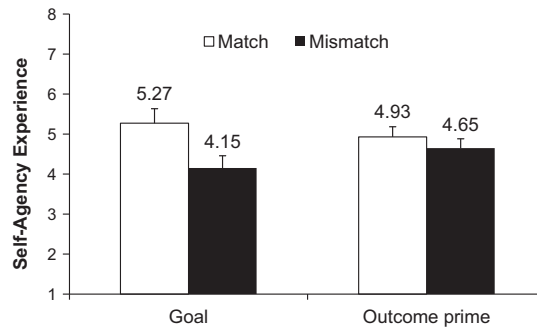
Fig. 3. Self-agency experiences as a function of Type of pre-activation and Matching for experiment 1b. Error bars indicate the standard error of the mean.

pre-activation, $F(1,54) = 1.18$, $p = .282$, $\eta\rho^2 = .02$, indicating that average self-agency experiences did not differ between the separate experiments or Types of pre-activation. However, the main effect of Matching was significant, $F(1,54) = 25.47$, $p < .001$, $\eta\rho^2 = .32$, showing that overall, outcomes that matched pre-activated information induced stronger agency experiences than when the outcomes mismatched this information. Furthermore, this effect was moderated by the Type of pre-activation, as indicated by the significant interaction of Type of pre-activation and Matching, $F(1,54) = 22.25$, $p < .001$, $\eta\rho^2 = .29$. Mean agency experiences are presented in Fig. 4.

The interaction shows a larger difference between match and mismatch conditions in goal than in outcome prime trials (Goal: $F(1,54) = 25.72$, $p < .001$, $\eta\rho^2 = .32$; Outcome prime: $F(1,54) = 12.94$, $p = .001$, $\eta\rho^2 = .19$). Furthermore, differences in agency experiences between the goal and prime trials are more pronounced in the mismatch condition, $F(1,54) = 16.20$, $p < .001$, $\eta\rho^2 = .23$, than in the match condition, $F(1,54) = 9.71$, $p < .001$, $\eta\rho^2 = .15$ (cf. Van der Weiden et al., 2013).

3.4. Discussion

The findings of two studies show the robustness of goal-based and prime-based agency inferences in a paradigm devoid of previous shortcomings in timings and exposure times. In Experiments 1a and 1b, both goals and outcome primes are presented in equivalent time windows before the presentation of the action-outcome, ensuring that both sources of information have equal opportunity to affect self-agency experiences. Results showed that, whereas both goals and primes affected experiences of agency, goal-based agency inferences more strongly relied on matching and mismatching information than prime-based agency inferences. These findings replicate previous investigations into goal-based and prime-based self-agency inferences (Aarts et al., 2005; Renes et al., 2013; Van der Weiden et al., 2013), lending credence to the idea that the differential effects for both routes are likely no artefacts of the specific paradigm employed in these studies.

However, in order to examine whether attentional control processes modulate these differential effects, more evidence is needed. Accordingly, Experiment 2 and 3 will add a working memory load manipulation to the task. Specifically, based on earlier work (Hon et al., 2013) we created a low working memory load condition in Experiment 2 by asking participants to remember two digits for the duration of a self-agency trial, after which they had to recall a specific digit of the digit span. This low load of working memory is expected to not affect goal-based and prime-based agency inference. However, as we had no prior knowledge about how heavy the digit span load would be in this specific agency inference task for more than two digits, we decided to explore the effects of both four and five digits. A next study (Experiment 3) would then serve to replicate the effects of working memory load on goal-based vs. prime-based agency inferences. As we argued in the introduction, applying a heavier working memory load was expected to reduce goal-based agency inferences, but not (or to a lesser extent) prime-based agency inferences.
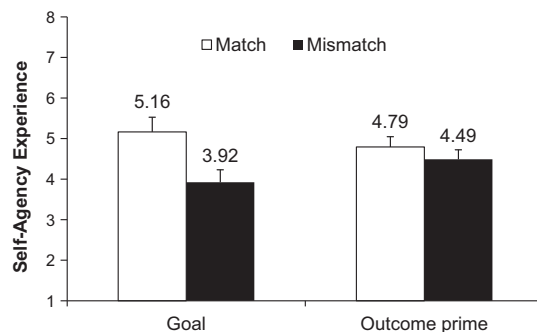

Fig. 4. Self-agency experiences as a function of Type of pre-activation and Matching, collapsed across Experiments 1a and 1b. Error bars indicate the standard error of the mean.

4. Experiment 2

4.1. Methods

4.1.1. Participants

Due to the exploratory nature of this experiment, and the lack of knowledge about the size of the specific interaction effect between Type of pre-activation and Working memory load, no power analysis could be performed and participant recruitment erred on the side of caution. Accordingly, 75 undergraduates were recruited to participate in this experiment and received a monetary reward or course credit for participation. One participant's data was lost due to a technical failure. Furthermore, one participant's data was excluded from further analysis because (s)he failed to respond to any of the digit span retrievals. Finally, like in Experiment 1b, three participants did not follow instructions, as they did not vary on agency ratings across the trials. These participants were also excluded from analyses. After exclusions, 70 participants (45 females; M_{age} = 22.06, SD = 3.13) were included in the analyses.

4.1.2. Procedure and self-agency task

The agency task was identical to the one in the previous experiments, with one exception. A working memory load manipulation was introduced in the goal and outcome-prime self-agency trials. Before each trial, participants were required to remember two (low load condition), four (medium load condition) or five (high load condition) digits for the remainder of the trial. The agency part of the trial then proceeded as in Experiments 1a and 1b, until the participant provided a self-agency rating. Then, participants were probed for free recall of one of the digits.

4.1.3. Events in a trial

With the addition of a digit encoding phase at the beginning of each trial and a digit retrieval phase at the end, each trial now consisted of seven phases. In the encoding phase, participants were presented with either two, four or five digits at the center of the screen, each digit separated with a space from the next. Digits ranging from 0 to 9 were randomly selected each trial, allowing no duplicates to maintain a similar level of difficulty across trials of each condition. The duration of this phase was dependent on the number of digits, allowing one second of exposure for each digit (i.e., two seconds in the low load condition, four in the medium load condition, and five in the high load condition).

In the digit retrieval phase, one of the digits was probed with a randomly selected question, querying a digit before or after another digit (e.g., in a digit span of 3 5, "what digit was presented before 5?" Or "what digit was presented after 3"). Irrespective of condition, the retrieval phase lasted a maximum of four seconds or until a response was given. After this, participants received one second of feedback regarding the accuracy of their answer. If no answer was given, the answer was classified as incorrect and the feedback instructed participants to respond faster.

In order to accommodate the increased length of the trials and the potential additional fatigue of the participants, the number of trials was reduced. Accordingly, the goal trials and outcome prime trials were presented in two separated (counterbalanced) blocks which each consisted of 48 randomly presented trials. In half of the trials, pre-activated color words corresponded with the actual outcome, whereas in the other half of the trials they did not correspond with this outcome. Furthermore, the working memory load levels were also evenly divided over the trials. Participants first practiced both types of trials in the counterbalanced order before the onset of the experiment (8 trials per practice block without the working memory load manipulation, then 4 trials including working memory load for the first block). After completing these practice trials participants completed the first type of pre-activation trials, followed by the second type of pre-activation trials (4 practice trials including the working memory conditions preceded this second block). In between the two blocks participants were allowed to have a break. In addition, participants paused for thirty seconds after completing every third (i.e., 16 trials) of each block of trials.

4.1.4. Manipulation checks

To ascertain a difference in working memory load between the low, medium and high load condition conditions, several measures were collected for analyses. First, upon completion of the task, participants received three questions probing the difficulty of each digit spans (i.e., "how difficult was it to remember two (or four/five) numbers throughout the trials?"; 9-point likert scale, ranging from 'not at all' [1] to 'very' [9]), in order to establish participants' subjective difficulties of engaging in the three different working memory load conditions. Furthermore, the response time to the working memory probes and the proportion of accurate working memory performance were assessed for each load condition (see also Hon et al., 2013).

4.2. Results

4.2.1. Manipulation checks

The subjective difficulty of remembering the digit spans, the response time to the working memory probes and the proportion of accurate working memory performance were subjected to a repeated measures ANOVA with Working memory load (Low vs. Medium vs. High) as a within-subjects factor. All analyses examined a linear trend effect of Working memory

load. First, the ANOVA yielded differences on the subjective measure of difficulty, $F(1,68) = 19.26$, $p < .001$, $\eta\rho^2 = .22$; participants reported that remembering 5 digits was more difficult ($M_{High} = 3.96$, $SD = 2.42$) than remembering 4 digits ($M_{Medium} = 3.07$, $SD = 1.85$) and that remembering 4 digits was more difficult than 2 digits ($M_{Low} = 2.64$, $SD = 2.13$); $t(69) = -4.10$, $p < .001$, and $t(69) = -1.94$, $p = .056$, respectively. Furthermore, there were strong differences between the load conditions on the response time to the working memory probes, $F(1,68) = 497.88$, $p < .001$, $\eta\rho^2 = .88$; participants were slower in the higher (5 digits) load condition ($M_{High} = 2166$ ms, $SD = 270$) than in the medium (4 digits) condition ($M_{Medium} = 2038$ ms, $SD = 280$) and they were slower in the medium condition than in the low (2 digits) load condition ($M_{Low} = 1413$ ms, $SD = 298$); $t(69) = -4.92$, $p < .001$, and $t(69) = -19.58$, $p < .001$, respectively. Finally, the ANOVA on the accuracy measure showed differences between conditions, $F(1,68) = 10.42$, $p = .002$, $\eta\rho^2 = .13$; participants were equally accurate in the high load condition ($M_{High} = 83.6\%$, $SD = 15.2$) and in the medium load condition ($M_{Medium} = 83.9\%$, $SD = 13.1$), but they clearly were less accurate in the medium load condition than in the low load condition ($M_{Low} = 89.2\%$, $SD = 8.4$); $t(69) = 0.26$, $p = .79$, and $t(69) = 3.28$, $p = .002$, respectively. Thus, whereas the 4 and 5 digit load conditions resulted in statistically indistinguishable effects on the accuracy measure, overall the pattern of findings on the three checks indicates that our working memory load manipulation was successful.

4.2.2. Self-agency experiences

Due to the absence of a key press within the interval of the action phase, 3.9% of the total number of trials was excluded from the analyses. Averaged self-agency experiences were subjected to a 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs Mismatch) by 3 (Working memory load: Low vs. Medium vs. High) repeated-measures ANOVA. The results yielded no main effect of Type of pre-activation, $F(1,69) = 0.44$, $p = .51$, $\eta\rho^2 = .01$, nor a main effect of Working memory load, $F(1,68) = 1.71$, $p = .20$, $\eta\rho^2 = .02$. The main effect of Matching was significant, $F(1,69) = 19.08$, $p < .001$, $\eta\rho^2 = .22$, prompting stronger self-agency experiences when pre-activated outcome information matched rather than mismatched action outcomes. This main effect of matching was qualified by a significant interaction with Type of pre-activation, $F(1,69) = 14.89$, $p < .001$, $\eta\rho^2 = .18$. In line with the previous findings, the effect of Matching was more pronounced for the goal-based agency inferences, $F(1,69) = 20.27$, $p < .001$, $\eta\rho^2 = .23$, than for the prime-based agency inferences, $F(1,69) = 4.01$, $p = .049$, $\eta\rho^2 = .06$.

Simple main effect analyses revealed that within the goal trials, there was a significant effect of Matching in Low, $F(1,69) = 20.65$, $p < .001$, $\eta\rho^2 = .23$, Medium, $F(1,69) = 21.21$, $p < .001$, $\eta\rho^2 = .24$, and High load conditions, $F(1,69) = 13.23$, $p = .001$, $\eta\rho^2 = .16$. With respect to our specific hypothesis, higher Working memory load reduced the effect of Matching at trend level as indicated by the interaction of Matching and Working memory load, $F(1,68) = 3.42$, $p = .069$, $\eta\rho^2 = .05$. The outcome prime trials also yielded an interaction of Matching and Working memory load, $F(1,68) = 4.25$, $p = .043$, $\eta\rho^2 = .06$. However, the pattern was found to be reversed: the high load condition showed a significant effect of Matching, $F(1,69) = 7.89$, $p = .006$, $\eta\rho^2 = .10$, whereas both the Medium, $F(1,69) = 1.94$, $p = .168$, $\eta\rho^2 = .03$, and Low levels, $F(1,69) = 0.29$, $p = .592$, $\eta\rho^2 = .00$, did not. These differential effects of working memory load on agency experiences within goal and prime conditions were corroborated by the three-way interaction between Type of pre-activation, Matching and Working memory load, $F(1,68) = 6.38$, $p = .014$, $\eta\rho^2 = .09$. Fig. 5 presents this three-way interaction effect on agency ratings. For clarity of interpretation, differences scores between match and mismatch trials for each condition are displayed.

4.3. Discussion

The findings in experiment 2 show that goals have a larger impact on self-agency inferences than primes. These findings replicate the results of Experiment 1. Furthermore, working memory load modulated self-agency experiences differently for both goals and primes. In the goal condition, high working memory load reduced the effect of matching compared to low working memory load, as was hypothesized. In the outcome prime condition, however, the data suggest that while the effect
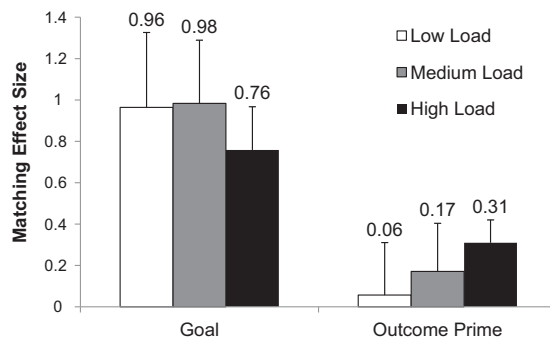

Fig. 5. Self-agency experiences of Experiment 2 as a function of Type of pre-activation and Working memory load. For clarity of interpretation, differences scores between match and mismatch trials for each condition are displayed. Error bars represent standard errors of the mean.

of matching is significant in the high load condition, the effect of matching is diminished in the medium and low load conditions. In light of the findings of Experiment 1, in which outcome priming shows an effect without load, this is an unexpected result. Importantly, the effect of matching in the high working memory load condition is significant, as is congruent with our hypothesis. We do not know yet whether the decline effect of matching in the low and medium conditions effect is a fluke, or an effect of our specific working memory manipulation in the agency task at hand. However, we have no other explanations that can be supported by the data. Instead of speculating about the origin of this unexpected finding, it is more important to verify whether this pattern holds in Experiment 3. Experiment 2 showed that contrasting the low and high working memory load conditions provided the clearest demonstration of the effects (both on the manipulation checks and self-agency ratings), therefore Experiment 3 will only include the low and high load conditions.

5. Experiment 3

5.1. Methods

5.1.1. Participants

Based on the effect size of the three-way interaction effect observed in Experiment 2 (Cohen's d_z = 0.30), and a power of 0.80 (α = 0.05), we would need 89 participants to replicate the effect. However, because we reduced the working memory load manipulation to two levels, we were also able to increase within participant power by doubling the number of trials (from 8 to 16) in each cell of the 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs. Mismatch) by 2 (Working memory load: Low vs. High) in the within participants design. Accordingly, we recruited 81 undergraduates who participated in the study and received a monetary reward or course credit for participation. In line with the previous experiments, six participants did not follow instructions and had to be excluded from analyses, as they did not vary on agency ratings across the trials. Hence, 75 participants (46 females; M_{age} = 20.73, SD = 3.44) were included in the final analyses.

5.1.2. Procedure and self-agency task

The working memory load manipulation was brought down to two levels, i.e., two or five digits (low vs. high working memory load, respectively). The number of trials per type of pre-activated outcome information was increased to 64 to increase power and allow for an equal distribution of trials per cell of the full design. This resulted in 32 trials per working memory load condition in each block, half of which had outcomes that matched pre-activated outcome-information, whereas the other half did not.

5.2. Results

5.2.1. Manipulation checks

The subjective difficulty of remembering the digit spans, the response time to the working memory probes and the proportion of accurate working memory performance were subjected to a repeated measures ANOVA with Working memory load (Low vs. High) as a within-subjects factor. All analyses yielded the expected main effect of Working memory load. First, participants reported that remembering five digits was more difficult than remembering two digits (M_{Low} = 2.92, SD = 1.98; M_{High} = 4.08, SD = 2.23; $F(1,74)$ = 21.46, p < .001, $\eta\rho^2$ = .23). Response times to digit probes were slower in the high load condition than in the low load condition (M_{Low} = 1321 ms, SD = 245 ms; M_{High} = 2166 ms, SD = 256 ms; $F(1,74)$ = 848.61, p < .001, $\eta\rho^2$ = .92). For the accuracy, participants were less accurate in the high load condition than in the low load condition (M_{Low} = 88.9%, SD = 9.1%; M_{High} = 83.4%, SD = 12.7%; $F(1,74)$ = 16.42, p < .001, $\eta\rho^2$ = .18). These findings thus indicate that attentional processes were more taxed in the high working memory condition than in the low working memory condition.

5.2.2. Self-agency experiences

Due to the absence of a key press within the interval of the action phase 3.8% of the total number of trials were excluded from the analyses. Averaged self-agency experiences were subjected to a 2 (Type of pre-activation: Goal vs. Outcome prime) by 2 (Matching: Match vs. Mismatch) by 2 (Working memory load: Low vs. High) repeated-measures ANOVA (see Fig. 6). The analyses yielded a main effect of Working memory load, $F(1,74)$ = 4.29, p = .042, $\eta\rho^2$ = .06, showing slightly lower self-agency experiences in the high load condition (see also Hon et al., 2013). Type of pre-activation did not show a main effect, $F(1,74)$ = 0.12, p = .732, $\eta\rho^2$ = .00. The main effect of Matching was significant, $F(1,74)$ = 47.4, p < .001, $\eta\rho^2$ = .39, showing stronger self-agency experiences when outcomes matched pre-activated information than when they mismatched such information. Furthermore, this pattern was stronger for goals than for primes, as indicated by the Type of pre-activation by Matching interaction, $F(1,74)$ = 37.1, p < .001, $\eta\rho^2$ = .33. Working memory load did not interact with neither Type of pre-activation, $F(1,74)$ = 2.47, p = .120, $\eta\rho^2$ = .03, nor Matching, $F(1,74)$ = 0.20, p = .653, $\eta\rho^2$ = .00.

With regard to our specific hypothesis for goal trials, it was found that while the effect of matching was significant in both low, $F(1,74)$ = 60.6, p < .001, $\eta\rho^2$ = .45, and high load conditions, $F(1,74)$ = 51.54, p < .001, $\eta\rho^2$ = .41, the higher working memory load did significantly reduce the effect of Matching as indicated by the interaction effect of Matching and Working memory load, $F(1,74)$ = 5.01, p = .028, $\eta\rho^2$ = .06. Within the outcome prime trials, no such interaction effect was found, $F < 1$; in
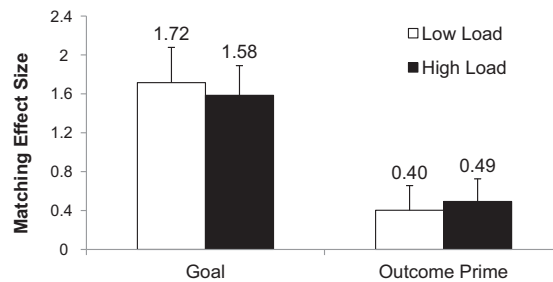
Fig. 6. Self-agency experiences of Experiment 3 as a function of Type of pre-activation and Working memory load. For clarity of interpretation, differences scores between match and mismatch trials for each condition are displayed. Error bars represent standard errors of the mean.

both the low, $F(1,74) = 9.59$, $p = .003$, $\eta\rho^2 = .12$, and high load condition, $F(1,74) = 10.05$, $p = .002$, $\eta\rho^2 = .12$, the effect of Matching was significant. This pattern was corroborated by a marginal three way interaction between Type of pre-activation, Matching, and Working memory load, $F(1,74) = 3.15$, $p = .080$, $\eta\rho^2 = .04$.

5.3. Discussion

Experiment 3 largely replicated the findings of Experiment 2. As expected, higher working memory load reduced goal-based inferences of self-agency. Furthermore, this reduction was not found in prime-based self-agency inferences.

In Experiment 2, the outcome prime condition showed unexpected results, where the effect of matching was reduced in the low load condition. In Experiment 3 however, the effect of matching showed comparable results to Experiment 1. This suggests that the unexpected finding in Experiment 2 might have been a fluke or may have been an artifact of the specific working memory manipulation (three levels) that we used in comparison to Experiment 3 (two levels). Most importantly, closer scrutiny of both goal and prime conditions in Experiment 3 showed the expected patterns in support of our hypotheses.

6. General discussion

Building on previous research that investigated self-agency experiences as a function of goals and primes, the present research was set out to examine whether goal-based agency inferences follow from a different process than prime-based agency inferences. Specifically, we suggested that goals (operationalized as sufficient amount of input of action-outcome information to form an explicit goal to produce the outcome) facilitates the recruitment of attentional control processes that monitor and process feedback about the progress of achieving the goal. Therefore, both matching and mismatching of the pre-activated action-outcome information with the actual action-outcome influences self-agency experiences in a profound way. Outcome-primes (operationalized as sufficient amount of input to automatically process action-outcome information but not to form a goal to produce the outcome) do not engage attentional control processes. Hence, when this primed information matches the outcome of an action it has a smaller impact on experienced self-agency.

To examine these ideas, we first replicated earlier research while employing a novel task that allow for a test of goal-based and prime-based self-agency inferences under equal circumstances of duration and timing of pre-activation of outcome information in the sequence of action performance and observing outcomes. The results of Experiment 1 indeed revealed a larger effect of matching for goals than for primes. The present study therefore provides a better test for the investigation of the unfolding of prime-based versus goal-based inferences.

Secondly, we used a working memory manipulation to test whether goal-based inferences used more attentional control than prime-based inferences. Although the observed effects are somewhat small and weak, the general gist of our findings is that with increased working memory load agency inferences were attenuated in the goal-based condition but not in the prime-based condition, supporting the notion that goal-based (vs. prime-based) agency inferences rely more heavily on attentional control processes. These findings partly replicate earlier findings (Hon et al., 2013), also showing that high working memory load decreased self-agency experiences. However, although these previous findings are an important first step, they only allowed the general conclusion that self-agency processing is dependent on cognitive resources. The present study extends these findings by ruling out the involvement of motor prediction effects (i.e., actions did not predict outcomes), and by varying the exposure to outcome information. Importantly, although our findings show that working memory reduces but does not cease goal-based agency inferences, self-agency processing was only modulated when inferences are based on goals, while self-agency processing was rather unaffected when the inference is based on primes.

The finding that working memory load reduces goal-based agency inferences lends credence to the notion that goal-based agency inferences make more use of higher order cognitive processes than prime-based agency inferences. This notion is substantiated by recent neuroscientific research, suggesting the involvement of a specific cortical network dedicated to goal-based self-agency inferences. Specifically, in a neuroimaging study, participants who inferred that they caused an

outcome to occur when the outcome matched their goal displayed increased activity in frontal and parietal regions such as the medial prefrontal cortex, bilateral superior frontal cortex and inferior parietal lobule (Renes, Van Haren, Aarts, & Vink, 2015). These findings are corroborated in an electroencephalography study to measure connectivity of brain areas (Dogge, Hofman, Boersma, Dijkerman, & Aarts, 2014). This study used a similar agency inference task to the one used in the present study, and showed strong connectivity between frontoparietal regions during goal-based agency inferences. Interestingly, this study also assessed prime-based agency inferences, and showed considerably weaker and more diffuse connectivity between frontoparietal regions during self-agency inferences as compared to when these inferences were goal-based. Although different in strength of connectivity, connectivity patterns analysis further showed directional flow from parietal to frontal regions in both goal-based and prime-based inferences, indicating that parietal regions communicate with frontal regions to arrive at the experience of agency (see also Nahab et al., 2011; for an account of the involvement of leading and lagging cortical networks for the translation of an observed outcome into higher order processing of agency).

Although our findings suggest that taxing attentional control does not compromise prime-based agency inferences, this does not mean to say that these inferences cannot be reduced or impaired. As argued before, because primed-based agency inferences rely on a well-communicated match between a primed outcome and an actual outcome, processes that hamper this communication might also reduce prime-based inferences. In line with this notion, recent research suggests that when people focus too much on the execution of motor movements (e.g., pushing a button), rather than on the occurrence of out-comes of their actions (e.g., produce a color-word), the effects of outcome priming on experienced self-agency over matching outcomes diminish (Belayachi & Van der Linden, 2010; Dannenberg, Förster, & Jostmann, 2012; Van der Weiden, Aarts, & Ruys, 2010). This suggests that when attention is not directed to the outcomes of one's own actions, agency inferences are less likely to follow from a match between primed and actual action-outcomes.

In addition to the importance of attending to outcomes of actions, neurobiological impairments that disturb communication within the neural network implicated in primed-based agency inferences may also reduce the establishment of prime-based agency inferences. Due to the inherent diffuse connectivity in the frontoparietal regions associated with prime-based self-agency inferences, the integrity of the frontoparietal fibers that broadcast the required outcome-information is probably vital, as primed information generally does not recruit cortical structures (Baars, 1988; Dehaene & Naccache, 2001). If these fibers are only subtly compromised, prime-based self-agency inferences might be compromised as well. In patients with schizophrenia – who as a part of their illness often exhibit difficulties in distinguishing one's own actions and outcomes from those of others – these vital frontoparietal regions are not properly connected (Ellison-Wright & Bullmore, 2009; Voineskos et al., 2010; Whitford, Kubicki, & Shenton, 2011). Consistent with this suggestion, a recent study indeed showed impairment in prime-based agency inferences in a group of patients with schizophrenia, but not in a healthy control group (Renes et al., 2013).

In conclusion, we observed that under conditions in which motor prediction signals cannot inform people about their sense of agency, goal-based self-agency inferences involve attentional control, whereas this is less the case when these inferences are prime-based. This observation may have implications for situations wherein we operate in a goal-directed fashion. For instance, in the context of law, moral judgments and human behavior, the experience of agency and responsibility are often thought to be intertwined (Frith, 2014; Greene et al., 2009; Haggard & Tsakiris, 2009); people are held responsible for actions that are commonly believed to be accompanied by agency. Accordingly, potential discrepancies between personal experiences and social norms and rules about agency and responsibility might occur when attentional resources are temporary usurped by other processes (e.g., distractions, mind wandering), thereby hampering the establishment of self-agency in goal-directed behavior. Whereas our findings do not directly address the relationship between the experience of agency and responsibility, it might be interesting for future research to study whether and how goal-based and primed-based agency inferences shape the experience of responsibility as a function of taxing attentional control. The present study might offer a test and starting point to examine this important and intriguing issue.

Acknowledgement

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