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Unconscious modulation of the conscious experience of voluntary control ☆

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Abstract

How does the brain generate our experience of being in control over our actions and their effects? Here, we argue that the perception of events as self-caused emerges from a comparison between anticipated and actual action-effects: if the representation of an event that follows an action is activated before the action, the event is experienced as caused by one's own action, whereas in the case of a mismatch it will be attributed to an external cause rather than to the self. In a subliminal priming paradigm we show that participants overestimated how much control they had over objectively uncontrollable stimuli, which appeared after free- or forced-choice actions, when a masked prime activated a representation of the stimuli immediately before each action. This prime-induced control-illusion was independent from whether primes were consciously perceived. Results indicate that the conscious experience of control is modulated by unconscious anticipations of action-effects.

Keywords: Experienced control; Priming; Subliminal; Action effects; Effect-anticipation; Agency; Illusion of control

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1. Introduction

The conscious experience of free will is a central feature of human self-perception. We usually feel that our conscious intentions cause our actions, which in turn produce desired effects in the world. Although the subjective feeling of control is an essential aspect of our self-conceptualisation as intentional agents, the mechanisms underlying this experience are not well understood (e.g., Haggard, Clark, & Kalogeras, 2002; Jeannerod, 2003; Lau, Rogers, Haggard, & Passingham, 2004; Sebanz & Prinz, 2006; Sirigu et al., 2004). Here, we argue that the conscious feeling of voluntary control is closely tied to our ability to represent future effects of our actions. William James was among the first to note that voluntary action is based on "…anticipation of the movements' sensible effects, resident or remote…" (James, 1890, p. 521; cf. Lotze, 1852). In a similar vein, Michotte identified "…our ability to foresee the result before it actually takes place…" as the main source of the experience of agency (Michotte, 1954/1963, p.10). More recently, Elsner and Hommel (2001) reported evidence suggesting that effect anticipations are based on bidirectional action-effect associations acquired in a two-stage learning process: first, behavioral acts are associated with the perceivable effects they bring about; later these associations form the basis for intentionally selecting actions that produce desired effects (cf. Goschke, 2003, 2004; Prinz, 1998, 2000).

Further evidence for the importance of sensory action effects in voluntary action control stems from experiments showing that subjects have poor awareness of specific parameters of voluntary movements and the proprioceptive feedback associated with movements, but rely primarily on sensory feedback about the intended effects in adjusting motor parameters to achieve a goal. For instance, subjects who were deprived from accurate visual feedback and instead received distorted feedback about the trajectory of a movement compensated for the deviation in order to produce the desired effect yet were not aware of this compensation (Fourneret & Jeannerod, 1998; Knoblich & Kirchner, 2004). This indicates that feedback about intended sensory effects plays a critical role in action control.

Our present investigation was motivated by the hypothesis that effect anticipations also play an important role in generating the conscious feeling of control. More specifically, we assume that if a sensory action effect is accurately anticipated before the action, individuals tend to experience the effect as self-caused, whereas in the case of a mismatch between anticipated and actual effect, the effect will be attributed to an external cause rather than to the self. Variants of this general idea can be found in a number of recent theories of willed action (e.g., Frith, 2005; see Haggard, 2005, for a review). For instance, Blakemore, Wolpert, and Frith (2002) postulated that during the execution of a voluntary movement a *forward model* computes predictions of the sensory consequences of one's movement. If the predicted consequences and the actual sensory feedback coincide, the representation of the sensory effect is attenuated and the effect is experienced as self-generated (Blakemore, Wolpert, & Frith, 1998, 2000).

Direct evidence that the experience of agency, that is, of being the originator of a sensory event, depends on the congruence between anticipated and actual sensory effects of an action was recently reported by Sato and Yasuda (2005). In their experiments, participants first learned that pressing a left or a right key was consistently followed after a constant delay either by a high or a low tone (the action effect). In a subsequent test phase the responses were either followed by the same tone as in the prior learning phase (congruent trials), or they were followed by the other (i.e., unexpected) tone (incongruent trials). Participants were instructed that the tones could be the result of their own action or the experimenter's action. The results showed that the self-reported degree to which participants felt that the tone was a consequence of their own action diminished when the effect tones were inconsistent with the learned action-effect mapping. Moreover, the sense of agency was reduced when the tone was presented at an unexpected delay, although in fact it was self-produced. These findings fit with the forward model theory of voluntary action mentioned above, according to which the execution of an action is accompanied by the generation of a prediction of the sensory consequences of the action, which is then compared with the actual consequences of the action (Blakemore et al., 1998, 2000; Frith, 2005). The higher the congruence between anticipated and actual action-effects, the stronger is the tendency to experience the effect as caused by one's own action.

On a more general level, Wegner (2002, 2004) proposed a theory of "apparent mental causation", according to which the experience of conscious will is the result of a causal *inference* that is based on anticipatory previews of actions and their effects (Wegner, 2003). Following Hume (1939), Wegner assumes that we cannot directly perceive causal links between our thoughts and our actions, but that we must infer mental causation from observed covariations between intentions and actions. Specifically, Wegner assumes that an action is experienced as caused by one's conscious thoughts when (1) a thought (typically an intention) occurs just prior to the action, (2) the thought is consistent with the action, and (3) there are no plausible alternative causes for the action. Conscious will is thus not based on the direct introspection of the causes of our actions, but reflects the perception of an *apparent* causal link between thought and action that results from anticipations of our actions and their effects. Importantly, the impression that one's thought caused an action is – like any causal inference – in principle fallible and the feeling of agency and authorship need not reflect the true causes of actions and their effects.

Empirical support for this theory stems from experiments by Wegner and his colleagues, in which they showed that participants can be led to experience an enhanced sense of authorship for action effects they did not in fact cause by priming thoughts about the action effects just prior to the action. For instance, Wegner and Wheatley (1999) found that inducing a thought about a potential action effect enhanced experienced authorship over the effect although the effect was in reality caused by someone else. Likewise, Aarts, Custers, and Wegner (2005) found that priming the location of an action effect enhanced participants' experienced control over the – in fact externally caused – effect.

The purpose of our study was twofold. First, we attempted to provide further evidence that an illusion of conscious control over an – objectively uncontrollable

– event which follows one's action can be induced by priming a representation of this event prior to the action. Secondly, we examined whether such a modulation of conscious control occurs even when the primed representation of the event remains completely unconscious (cf. Eimer & Schlaghecken, 2003; Merikle & Reingold, 1998; Merikle, Smilek, & Eastwood, 2001; Naccache & Deheane, 2001). To this end, we designed a control-judgment task, in which on each trial participants performed one of two actions, which were followed by one of two visual stimuli. By pressing keys, participants either had limited (Experiment 1) or no control at all (Experiment 2) over which stimulus appeared on a given trial. Immediately before each action, a masked prime-stimulus was presented which was either congruent or incongruent with the post-action stimulus. Importantly, in contrast to most previous studies on the priming of action effects we adopted a strict forced-choice recognition criterion to ensure that the primes remained fully unconscious.

Our main prediction was that subliminally priming the representation of the post-action stimulus before each action would lead participants to overestimate the degree of control they had over the stimuli, compared to when no or even an incongruent stimulus representation was primed. The critical idea underlying this prediction is that the mechanism that normally computes *internal* predictions of action effects may be "tricked", when an *external* prime activates an "effect"-representation immediately prior to a voluntary action, especially when in reality the actual effects are unpredictable. If this prediction turns out to be correct, it would constitute strong evidence that the conscious experience of agency depends on the congruency between an (unconsciously activated) effect representation and the actual "effect" following the action. In Experiment 1, this prediction was tested in a forced-choice task, whereas in Experiment 2, participants were free to choose on each trial which action they performed.

2. Experiment 1

In Experiment 1, we investigated whether subliminal priming of stimuli, which followed participants' actions as potential action-effects, systematically affects the degree to which participants felt to control these stimuli by their actions. In reality, participants had only a limited degree of control over these stimuli. To examine whether the presumed modulation of the conscious experience of control occurs on an unconscious level, the effect-primes were presented very briefly and masked such that they were not consciously perceived.

2.1. Method

2.1.1. Participants

Thirty undergraduates (24 female, 27 right-handed) from the Dresden University of Technology, aged 19–34 years (mean 23.4 years) participated for € 4 or course credit. All had normal or corrected to normal vision and were naïve to the purpose of the experiment within the limits of informed consent.

2.1.2. Apparatus, materials, and procedure

Participants were seated 60 cm from a 17 in. monitor (75 Hz). Stimulus presentation and response recording were controlled by a PC and synchronized with the vertical retrace signal of the monitor. The experiment consisted of three tasks.

2.1.2.1. Control-judgment task. First, participants performed six blocks of a forced-choice reaction task in which they had to press either a left or right key which were mapped to two imperative stimuli. After each key-press one of two alleged effect-stimuli appeared. At the end of each block participants judged the degree to which they thought they had controlled by their key-presses which effect-stimulus appeared.

Each trial of the forced-choice task began with the presentation of a forward-mask (150 ms duration) which was followed by a prime (30 ms duration) and a backward-mask (17 ms duration) (see Fig. 1). The primes consisted of left- and right-pointing arrows ("<<<<" or ">>>>") which were 0.4 cm in height and 3 cm in width. The mask was composed of left- and right-pointing arrows superimposed on each other and measured 0.8 cm × 4.5 cm. The mask was followed by one of two imperative target-stimuli ("#" sized 0.5 cm × 0.8 cm or "+" sized 0.5 cm × 0.5 cm) which was presented for 50 ms and replaced by a blank screen that remained visible until a response was made. Participants were instructed to press with their index and middle fingers of their dominant hand one of two keys (vertically arranged on the keyboard) to indicate which of the two imperative target stimuli ("#" or "+") had appeared on the screen. Stimulus-response mapping was counterbalanced across participants. Immediately after the response either left- or right-pointing arrows appeared for 500 ms as alleged effects of the key-press. Key to effect-stimulus assignment was counterbalanced across participants. After a 1 s delay the next trial started. All stimuli were presented in black on a grey background.

Participants were asked to try to find out whether by pressing the one or other key they could control which of the two effect-stimuli occurred. The actual contingency between participants' key presses and the alleged effects was imperfect: in 75% of

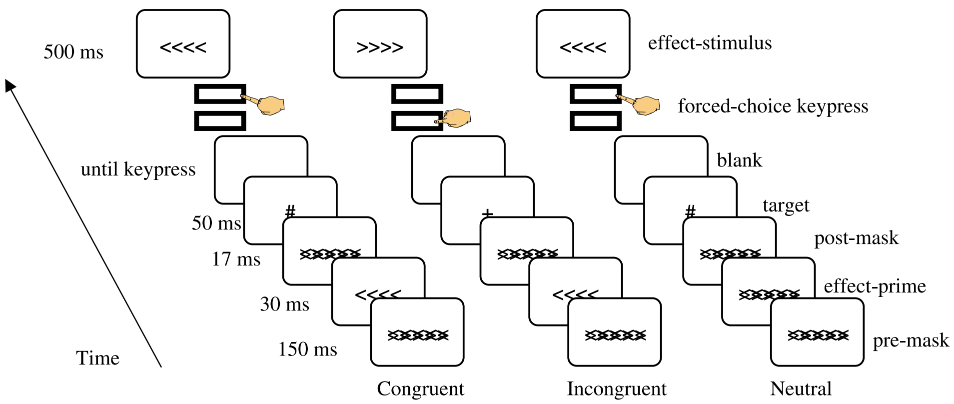

Fig. 1. Control-judgment task of Experiment 1. Sequence and durations of events on a trial in Experiment 1 for the three conditions of prime-effect-congruity (congruent, incongruent and neutral).

trials, a particular effect-stimulus appeared when a particular imperative stimulus had been presented; in the remaining 25% of trials, the other effect-stimulus appeared. Stimuli-assignment to probabilities was counterbalanced across participants. Thus, if a participant always pressed the correct key, there was also a limited contingency between key-presses and effect-stimuli such that each of the two key-presses was followed by one particular effect-stimulus in 75% of trials.

The critical independent variable was the relationship between the primes that were presented before each response and the effect-stimuli appearing after each response. As can be seen in Fig. 1, this relation was either *congruent*, (e.g., a left-pointing arrow effect following a left-pointing arrow prime), *incongruent* (e.g., a left-pointing arrow effect following a right-pointing arrow prime), or *neutral* (e.g., a left-pointing arrow effect following a neutral prime, which consisted of a superimposition of left- and right-pointing arrows). The three prime-effect relations were realized in separate blocks each consisting of 40 trials. Each participant performed two blocks with only congruent, two with only incongruent and two with only neutral prime-effect pairs. Order of conditions was counterbalanced across participants.

After each block participants received a questionnaire to rate how much control they thought they had over whether the arrows were pointing to the left or right on a scale ranging from 0% (no control) to 100% (complete control), (cf. Alloy & Abramson, 1979). Control judgments were predicted to be higher on congruent than on neutral trials, and higher on neutral than on incongruent trials.

2.1.2.2. Forced-choice priming task. To assess whether the masked primes had in fact activated the representation of their shapes, a forced-choice priming task was accomplished. Materials were the same as in the control-judgment task except that the stimuli that were used as imperative stimuli ("+", "#") in the control-judgment task were now replaced by the former effect-stimuli (left- and right-pointing arrows). No further effect-stimuli appeared after the key-presses. On each trial the forward mask (150 ms duration) was followed by a prime (30 ms duration), the backward mask (17 ms duration), and a target (50 ms duration) which was replaced by a blank screen remaining visible until a response was made. Participants were instructed to press with the index- and middle-fingers of their dominant hand as fast and as accurate as possible one of two vertically arranged keys to indicate whether the target-arrows were left- or right-pointing (key-target mapping was counterbalanced across participants). The ITI was 1 s. Prime-target pairs were congruent, incongruent or neutral. After 18 practice trials, 60 congruent, 60 incongruent, and 60 neutral trials were presented in random order. Responses were expected to be faster and more accurate after congruent compared to neutral or incongruent trials (Neumann and Klotz, 1994).

2.1.2.3. Awareness questionnaire and prime-identification task. Participants' awareness of the primes was determined both with respect to a subjective and an objective criterion (Merikle et al., 2001; Eimer & Schlaghecken, 2003). First, participants were asked on a questionnaire whether at any point they had seen anything on the monitor except for the mask and the effect-stimuli, and if so, what they had seen (subjective criterion of prime awareness). To assess prime-perceptibility according to an objective criterion, a forced-choice prime-identification task was conducted. Materials were the same as in the response-priming task except targets were now substituted by a question mark in black font sized 0.8 cm × 0.4 cm. Each trial commenced with the forward mask (150 ms duration), which was followed by a prime (30 ms duration), the backward mask (17 ms duration) and the question mark (50 ms duration) which was replaced by a blank screen remaining visible until a response was made. On 80 trials (40 trials each prime, the neutral prime was omitted) participants indicated whether a left- or right-pointing arrow-prime had been displayed by pressing one of the two vertically arranged keys on the computer keyboard. Primes were presented in random order. Performance was expected to be at chance level.

2.2. Results and discussion

Two participants who declared identification of the masked primes were excluded from the analyses. The remaining participants' mean rate of correctly identified primes in the prime-identification task was 50.8%, which was not significantly different from 50% chance ($p > .1$). Nevertheless, experienced control in the control-judgment task was substantially modulated by the masked primes. A repeated measures analysis of variance (ANOVA) revealed a highly significant effect of prime-effect congruity, $F(2,54) = 7.76$, $p < .002$, reflecting the fact that control was judged higher after blocks with congruent compared to incongruent or neutral prime-effect pairs (Fig. 2, left panel). A planned comparison showed that control-judgments were reliably higher on congruent than on incongruent trials, $t(27) = 2.74$, $p < .02$. This effect could not be attributed to differences in participants' responses in the different conditions,

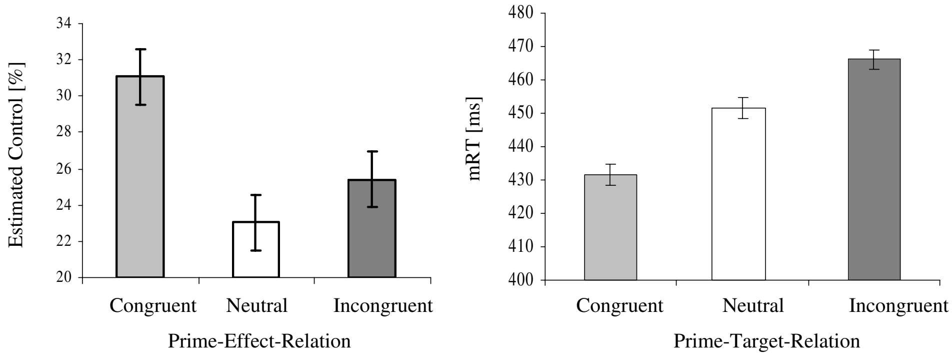

Fig. 2. Results of Experiment 1. Mean control-judgments in the control-judgment task as a function of prime-effect congruity (left panel) and mean RTs in the forced-choice priming task as a function of prime-target congruity (right panel) in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding comparison between prime-effect congruity conditions (Loftus & Masson, 1994).

as mean RT ($M = 668$ ms; $SD = 148.47$) and mean error rate ($M = 4.5\%$, $SD = 5.06$) did not significantly differ between congruity conditions. On a descriptive level, control-ratings were lower on neutral compared to incongruent trials. However, this difference was not significant ($p > .2$).

To obtain independent evidence that the masked primes were in fact processed unconsciously and did activate the representation of their shape, we analyzed RTs for correct responses in the forced-choice priming task (RTs exceeding 1500 ms were excluded). A repeated measures ANOVA yielded a highly significant main effect of congruity, $F(2,54) = 34.80$, $p < .001$, which reflected the fact that mean RT was faster on congruent than on neutral trials, $t(27) = -4.52$, $p < .001$, and faster on neutral than on incongruent trials, $t(27) = 3.53$, $p < .01$ (Fig. 2, right panel). Error rates, while on average being very low ($M = 2.95\%$, $SD = 2.61$), mirrored this pattern with participants committing significantly less errors on congruent than on incongruent trials, $F(2,54) = 3.60$, $p < .04$.

In conclusion, although the primes were not accessible to conscious awareness as indicated by chance performance in the forced-choice identification task, they were clearly processed unconsciously and – most importantly – they modulated experienced control. When the representation of the particular shape that appeared as an alleged effect of participants' action was subliminally primed before the action, participants experienced a significantly higher degree of control over the effect-stimuli.

3. Experiment 2

Experiment 2 attempted to substantiate and extend the findings of Experiment 1 in three ways. First, we examined whether masked priming of alleged effect-stimuli modulates the degree of experienced control over these stimuli also when the actions are freely chosen by the participants. To this end, the control judgment task of Experiment 1 was modified such that participants now freely chose whether to press a left or a right key-press whenever they received an unspecific go-signal. Second, we investigated whether the prime-induced modulation of conscious control occurs even when there is no systematic correlation between participants' actions and the stimuli appearing subsequently as alleged action-effects. Third, we addressed the question whether anticipatory priming of an unconscious effect-representation affects conscious control not only on a perceptual, but also on a more abstract conceptual level of processing. Therefore in Experiment 2, we used *semantic* stimuli (color words) to prime unconscious representations of stimuli (colored circles). As in Experiment 1, participants first performed six blocks of the – modified – control-judgment task, which was followed by the forced-choice priming task and finally the assessment of prime-perceptibility.

3.1. Method

3.1.1. Participants

Sixty-seven undergraduates (43 female, 63 right-handed) from the Dresden University of Technology participated for partial fulfillment of course credit or € 4 after they had given their written informed consent. They were on average 22 years old (range 19–35), had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

3.1.2. Apparatus, materials, and procedure

3.1.2.1. Control judgment task. The apparatus was the same as in Experiment 1. Primes consisted of the words BLUE (German: BLAU), YELLOW (German: GELB), and the non-word AGLB (used as a neutral prime) written in capital letters and measuring 0.6 cm in height and 2 cm in width. The mask was a meaningless letter string (ORTFX) sized 0.8 cm × 3 cm. Primes and mask were presented in black font on a white background. The effect-stimuli consisted of a blue and a yellow circle both of which were 2.5 cm in diameter.

Each trial started with the presentation of a prime (50 ms duration), which was replaced by the mask (100 ms duration) appearing simultaneously with an auditory go-signal (a brief 300 Hz-tone presented over head-phones). The mask was followed by a blank screen remaining visible until a response was made. Participants were instructed to freely choose to press either a left or a right key as soon as they had received the go-signal. They were asked to press both of the keys approximately equally often and to avoid systematic alternations or runs. Immediately after the response, either a blue or a yellow circle appeared and remained on the screen for 2 s as the alleged "effect" of the key-press. Participants were asked to try to find out by pressing the left or the right key whether they could control which of the two colored circles appeared.

Actually, there was *no* correlation between participants' freely chosen key-presses and the colors of the circles. Instead, one of the colors appeared with a probability of 75%, while the other appeared with a probability of 25%, *irrespective* of which key was pressed. Color-assignment to probabilities was counterbalanced across participants. Thus participants had *no control* over which colored circle appeared. The critical independent variable was the relation between the meaning of the prime words and the color of the circles that appeared as alleged effect stimuli. This relation was either *congruent*, (e.g., a blue circle following the prime word "BLUE"), *incongruent* (e.g., a blue circle following the prime word "YELLOW"), or *neutral* (e.g., a blue circle following the non-word-prime "AGLB"). The three conditions of prime-effect congruity were realized in separate blocks by 40 trials. Each participant performed two blocks with only congruent, two with only incongruent, and two with only neutral prime-effect pairs. Order of conditions was counterbalanced across participants Fig. 3.

After each block, participants rated how much control they thought they had over which of the two colored circles had appeared after their key-presses on a scale ranging from 0% (no control) to 100% (complete control). As in Experiment 1, we expected control judgments to be higher for congruent compared to incongruent or neutral prime-effect pairs, even though there was *no* systematic correlation between participants' key-presses and the circle colors.

3.1.2.2. Forced-choice priming task. After the control-judgment task, we assessed whether the masked primes did in fact activate the representation of their meaning in

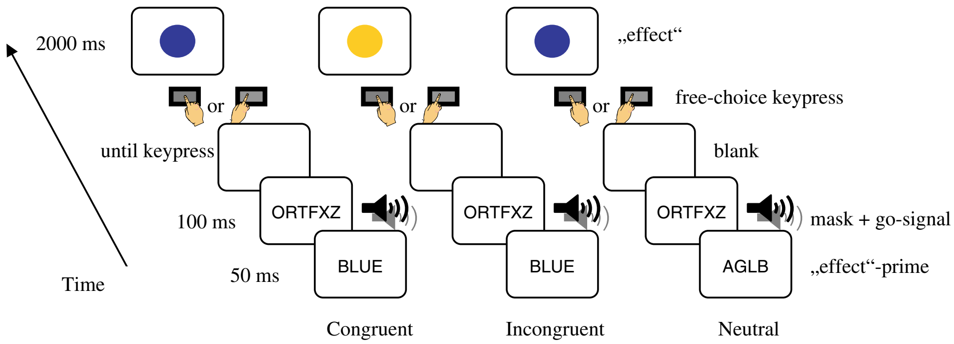

Fig. 3. Control-judgment task of Experiment 2. Sequence and durations of events on a trial in Experiment 2 for the three conditions of prime-“effect”-congruity (congruent, incongruent and neutral).

a forced-choice priming task. Materials were the same as in the control-judgment task. Each trial consisted of a prime (50 ms duration), the mask (100 ms duration), and a target (one of the color circles). Prime-target pairs were congruent, incongruent or neutral. The ITI was 1 s. Participants were instructed to press as fast and as accurate as possible a left or right key to indicate whether the target was blue or yellow. Key-target mapping was counterbalanced across participants. After 18 practice trials, 20 congruent, 20 incongruent, and 20 neutral trials were presented in random order.

3.1.2.3. Awareness questionnaire and prime-identification task. Prime-perceptibility was assessed via a questionnaire (see Experiment 1) and a prime-identification task using the same materials as in the priming task except that targets were now omitted. The prime-identification task comprised 33 trials (11 for each of the three primes) presented in a randomized order. Each trial began with the presentation of a prime (50 ms duration) which was followed by the mask (100 ms duration) and a blank screen remaining visible until participants had pressed the left-, the right-, or the space-key to indicate or guess the identity of the preceding prime-stimulus.

3.2. Results and discussion

Participants were classified as aware (“detectors”) or unaware (“non-detectors”) of the primes depending on whether their performance in the prime-identification task was above or below the median rate (51%) of correctly identified primes. Non-detectors ($N = 30$) identified on average 37% of the primes correctly, which was not significantly different from chance (33%), $p > .08$. Detectors ($N = 36$) identified on average 67% correctly which was substantially better than chance, $t(35) = 15.5$, $p < .001$. (Data from one participant who reported conscious identification of the primes, but paradoxically performed far below chance level in the prime-identification task were discarded).

Both detectors and non-detectors judged their control over the alleged effect stimuli to be higher after blocks with congruent compared to incongruent prime-"effect" pairs (Fig. 4, left panel). A mixed 3 (congruity) × 2 (prime awareness) ANOVA with control-judgments as the dependent variable revealed a significant effect of congruity, $F(2,128) = 3.34$, $p < .04$, but neither a main effect of prime awareness ($p > .1$) nor an interaction of the two variables ($p > .8$). On a descriptive level control judgments were somewhat lower for the detectors compared to non-detectors (possibly reflecting the fact that conscious perception of the primes led detectors to speculate about the purpose of the primes and to proceed more strategically in the experiment). Importantly, the modulating impact of the primes on experienced control (i.e., the difference between control-judgments for congruent compared to incongruent trials) was of almost identical magnitude for detectors and non-detectors.

That the meaning of the masked primes was in fact processed also when the primes remained unconscious was substantiated by the forced-choice priming task, in which mean RT for correct responses was lower on congruent than on neutral trials, and lower on neutral than on incongruent trials (Fig. 4, right panel). A mixed 3 (congruity) × 2 (detection group) ANOVA yielded a significant effect of congruity, $F(2,128) = 11.43$, $p < .001$, but neither an effect of prime awareness ($p > .5$), nor an interaction of the two variables ($p > .4$). Error rates were very low (2.8%, $SD = 3.72$) and did not significantly differ between congruity conditions ($p > .5$).

In conclusion, the pattern of results of Experiment 1 was almost perfectly replicated in Experiment 2, although participants freely chose which action to perform and although there was no contingency between their actions and the alleged effect-stimuli. The degree of experienced control was again substantially modulated by the masked primes, and this effect was independent from whether participants were aware or unaware of the primes according to an objective forced-choice criterion. Even though participants now performed freely chosen actions and had no control at all over the alleged "effect" stimuli, they judged their control significantly higher after blocks with congruent compared to neutral or incongruent prime-"effect" pairs. That

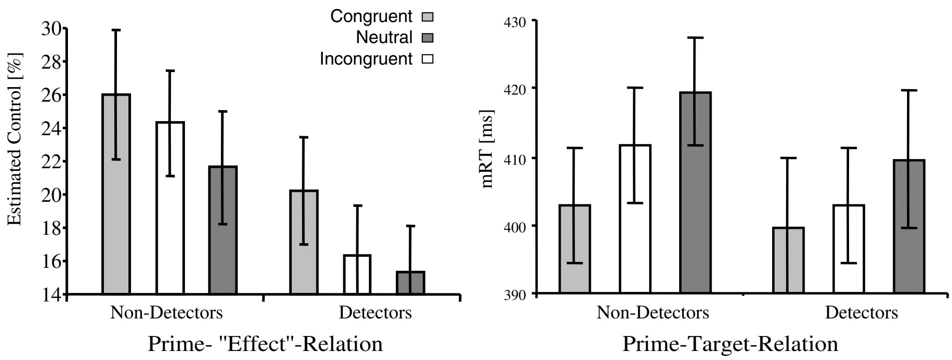

Fig. 4. Results of Experiment 2. Mean control-judgments in the control-judgment task as a function of prime-"effect" congruity (left panel) and mean RTs in the forced-choice priming task as a function of prime-target congruity (right panel) in Experiment 2, for participants classified as 'non-detectors' or 'detectors' depending on their performance in the prime-identification task. Error bars represent standard errors.

this effect occurred with semantic “effect”-primes (color words) reveals that the impact of masked effect-primes extends to a conceptual level of processing.

4. General discussion

In two experiments subliminal “effect”- primes significantly influenced participants’ conscious experience of being in control over sensory events following their actions. This prime-induced modulation of conscious control occurred even when in reality the alleged effect-stimuli were completely uncontrollable. Moreover this result was obtained even when the masked primes remained fully unconscious, which indicates that anticipations of alleged action-effects need not be conscious to modulate the experience of control. Rather, the subjective impression of having caused an effect by one’s own action was systematically influenced by representations of possible action effects that remained below the threshold of conscious awareness. The influence of the masked primes on control experience was not restricted to primes that were physically identical to the alleged effect-stimuli, but also occurred for semantic primes that were related to the effect-stimuli on a conceptual level. These findings provide strong support for our hypothesis that the subjective experience of control over sensory events emerges from an unconscious comparison between actual and anticipated effects of one’s actions: if anticipated and actual effect of an action match, there is an increased tendency to experience the effect as self-caused, whereas a mismatch between anticipated and actual effect increases the tendency to attribute the effect to an external cause.

Our results are thus generally consistent with Wegner’s (2002, 2003, 2004) theory of apparent mental causation, according to which the experience of conscious will rests on a fallible causal inference that is based on the consistency between previewed and actual actions or action-effects. Moreover, our findings are consistent with and extend recent results by Aarts et al. (2005) who found that the feeling of control over in fact externally caused action effects was enhanced when the location of the effects was primed subliminally. Our present findings extend previous studies in at least three respects. First, we obtained clear evidence for a modulating impact of effect-primes on experienced control even if the primes remained unconscious according to a strict forced-choice recognition criterion (rather than a retrospective self-report). Second, our results show that an illusion of control can be induced by priming representations of alleged action-effects before *freely chosen* actions (rather than externally triggered responses). Finally, our results show that the influence of unconscious effect-representations on experienced control is not restricted to the priming of the location of an action effect, but also holds for primes activating representations of the shape or meaning of effect-stimuli.

4.1. Which mechanisms mediate the influence of unconscious effect-primes on conscious control?

On a theoretical level, the present findings raise the question of how the match between anticipated and alleged actual effects could have influenced experienced control although the anticipatory representation of the effect remained unconscious. One possible mechanism that may underlie the unconscious modulation of conscious control is suggested by recent evidence indicating that the representation of a correctly predicted sensory effect of an action is *attenuated* and experienced as less intensive (Blakemore, 2003; Blakemore et al., 2000; Frith, 2005; Frith, Blakemore, & Wolpert, 2000). For instance, self-produced tactile stimulations are experienced as less intense compared to when the same stimulation is externally produced (Shergill, Bays, Frith, & Wolpert, 2003; Weiskrantz, Elliott, & Darlington, 1971). Moreover, the perceived intensity of self-produced tactile stimulations increases if a temporal delay is inserted between participants' actions and the tactile effects produced by these actions, presumably because the effects are less precisely predicted (Blakemore, Frith, & Wolpert, 1999). Furthermore, functional imaging studies have revealed that self-administered touches produce less activation in somatosensory and parietal cortex (Blakemore et al., 1998; Weiller et al., 1996). Importantly, sensory attenuation is not restricted to tactile experiences, but appears to hold more generally for perceptual experiences following a movement (see Frith, 2005, for a review).

Sensory attenuation of self-generated sensory stimulation presumably reflects the fact that correct predictions of the sensory effects of voluntary movements are generated on the basis of the motor system's execution commands. This is consistent with current theories of intentional action control (e.g., Blakemore et al., 2002; Haggard, 2005) which are based on the assumption that during goal-directed action an "inverse model" maps a goal representation to motor commands that are suited to produce a desired effect and which are then sent to the effectors. Simultaneously, an efference copy of the motor command is passed on to an "internal predictive model", which computes predictions of the sensory effects of the movement, even before feedback from the actual execution of the movement is received, allowing for rapid adjustments of the movement. If the predicted consequences and the actual sensory feedback coincide, the representation of the sensory effect is attenuated and the effect is experienced as self-generated (Blakemore et al., 1998, 2000; Sato & Yasuda, 2005). In contrast, if a sensory effect is externally generated, the forward model generates a less precise prediction, which leads to a reduced or no attenuation of the sensory effect-representation and thus an increased tendency to ascribe the effect to an external cause. Consistent with this assumption, it has been observed that the attenuation of self-caused sensory experiences was absent in schizophrenic patients experiencing delusions of alien control (Blakemore et al., 2000). Moreover, schizophrenic patients reporting delusions of control also showed abnormally high activity in parietal cortex during self-produced voluntary movements (Spence et al., 1997), which might reflect reduced attenuation of sensory feedback. This may explain why for these patients voluntary movements sometimes feel like passive movements which are controlled by alien forces (cf. Frith, 2005).

Applied to our experiments, these considerations suggest that subliminal effect-primes presumably produced an analogous attenuation of the sensory representation of the effect-stimuli that followed our participants' actions. On congruent trials, this prime-induced sensory attenuation of the effect-stimuli may have increased our participants' tendency to experience the stimuli as effects of their own actions, even if the primes remained below the threshold of conscious awareness. Conversely, when an incorrect action effect was primed (on incongruent trials in our experiments) there should have been no sensory attenuation and thus a more intense sensory representation of the actual effect-stimuli. That subliminal primes can indeed cause a sensory attenuation of subsequent stimuli is supported by neuroimaging findings showing that stimuli preceded by congruent masked primes were associated with a reduced level of activation compared to incongruently primed stimuli (Dehaene et al., 2001). In conclusion, while sensory attenuation appears to be a plausible explanation for the prime-induced modulation of the experience of control in our experiments, it is clearly up to further investigation to obtain more direct evidence for this interpretation. Moreover, it will be an important issue for future research to investigate in more detail to what degree experienced control results from unconscious effect-representations and under which conditions conscious anticipations of action effects contribute to the experience of voluntary control.

4.2. Is conscious will an illusion?

Does the fact that the conscious experience of control is based on a fallible causal attribution imply that conscious will is an illusion (as has been argued eloquently by Wegner, 2002)? The answer to this question depends critically on what one means by an illusion in this context. Clearly, our own as well as related findings reviewed in this paper provide convincing evidence against a naïve "Cartesian" view according to which the experience of agency and voluntary control rests on a privileged and incorrigible introspective access to the causes of our actions and their effects. As was already noted by David Hume (1739), we can not directly perceive cause-effect relations, but rather *infer* them from the observation of systematic relations between events. Likewise our experience that our conscious intentions cause our actions and that our actions cause certain effects emerges from a fallible causal attribution. The present results indicate that this attribution does not only involve inferences based on conscious expectations about the likely causes of actions, but is also modulated by unconsciously computed predictions of action effects. The fact that the processes that compute predictions of immediate action effects can operate unconsciously may explain why from the phenomenological perspective of the first person the experience of agency and voluntary control often seem so immediate and intuitively evident. It may elucidate why we become aware of the fact that our cognitive system continuously computes predictions of the sensory consequences of our actions only if these predictions fail and we are confronted with an unexpected action effect. Nevertheless, despite its apparent intuitive immediacy, like all causal attributions the processes underlying the feeling of agency are clearly prone to error and may under certain circumstances cause the mistaken impression that one is the originator of an effect which in reality was beyond one's control. In *this* sense one may indeed consider the conscious experience of agency and volition as an "illusion". As Wegner (2002, p. 2) notes: "conscious will is an illusion… in the sense that *the experience of consciously willing an action is not a direct indication that the conscious thought has caused the action*".

However, in our view this does *not* imply that the conscious experience of voluntary control is an illusion in the sense that it always deludes us about the causes of our actions and their effects (at least this follows no more and no less than it follows from the existence of perceptual illusions that perception is always deluding us; Goschke & Walter, 2005a, 2005b). We rather propose that the cognitive processes underlying the experience of voluntary control (in particular, the prediction of action effects and the comparison of predicted and actual sensory consequences of one's actions) constitute highly adaptive mechanisms that usually provide us with valid information about whether an event was caused by one's own action or by some external force. It appears unlikely that such a mechanism would have evolved if it constantly deceived organisms about the causes and effects of their actions. Rather, by continuously comparing predicted with actual action-effects we learn to anticipate increasingly better, which effects are caused by which actions under which conditions (Hoffmann, 1993) and thereby learn to infer correctly, whether an event was caused by *us* or some external force.

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