Minimising motor mimicry by myself: Self-focus enhances online action control mechanisms under motor contagion

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ABSTRACT

Ideomotor theory of human action control proposes that activation of a motor representation can occur either through internally intended or externally perceived actions. Critically, sometimes these two ways of eliciting a motor response may be conflicting, for example when intending one action and perceiving another, necessitating the recruitment of enhanced action control processes to avoid motor mimicry. Based on previous evidence, suggesting that reduced motor mimicry is associated with self-related processing, we aimed at enhancing these action control mechanisms during motor contagion experimentally by an induction of self-focus. In two within-subjects experiments, participants had to enforce their action intention against an external motor contagion tendency, either under heightened or normal self-focus. As predicted, self-focus reduced motor mimicry under both induction methods. Our findings indicate that self-focus is able to enhance online action control mechanisms needed to resist unintentional motor contagion, thus enabling a modulation of automatic mirroring responses.

According to the ideomotor account of action control, voluntary actions are controlled by their perceivable consequences (James, 1890), as performing of an action leads to an association between the action and its perceivable consequences through learning and thus form the basis for motor representations (Prinz, 1997). Motor representations are anticipations of the sensory feedback resulting of the action they represent, so that internally generated intentions (i.e. thinking of the desired sensory action-effects) can immediately be translated into the matching motor representation. However, because of this inherent property of motor representations, merely observing a movement automatically activates the corresponding motor plan. Hence, not only our own intentions, but also perceived actions have the power to induce a corresponding action representation and a strong imitative tendency for its execution in the observer (Greenwald, 1970, 1972). For example, people often unconsciously mimic facial expressions (Dimberg et al., 2000) and bodily movements of interaction partners (‘chameleon effect’, Chartrand & Bargh, 1999). Similarly, neuroscientific evidence has shown that observing an action activates the same set of ‘mirror’ regions involved in the execution of this particular movement in both macaque monkeys (Rizzolatti & Craighero, 2004) and humans (Buccino et al., 2001), and can elicit higher motor-evoked potentials from the muscle responsible for the observed movement (Fadiga et al., 2005; Strafella & Paus, 2001).

Nevertheless, automatic mimicry of observed behaviour is not the default behaviour in our day-to-day behaviour, but overt imitation rather depends on the current intentions and goals of the observer and the situational context. For example, seeing someone smiling at me normally leads involuntary to the same response (Dimberg et al., 2000), but for instance my knowledge of his intentions (e.g. being deceptive) or the circumstances (e.g. being at a funeral) might lead to the inhibition of the automatically activated motor representation of this behaviour. However, motor contagion is usually compelling and involuntary, so that sometimes we might have problems to resist, in this case smiling at a funeral, such automatically induced motor mimicry by perception. Hence paradoxically, the side-effect of ideomotor action control, namely automatic activation of the corresponding motor representation and induction of motor mimicry via action perception, can hamper the concurrent planning and execution of one's own voluntary, goal-directed actions. For example, in the 'imitation-inhibition task' (Fig. 1A), perceiving a movement on a computer monitor, while performing another, opposite movement, led to an interference effect, namely slower reaction times on such incongruent compared to congruent trials (i.e. perceiving the same movement) (Brass et al., 2000). Motoric conflicts between internally and externally induced action representations thus necessitate the involvement of increased action control mechanisms.

Previous research has indicated that these action control mechanisms rely on key processes specifically dedicated to distinguish one's own action from someone else's action and to represent intentions of oneself and others' (Brass & Spengler, 2008). A recent fMRI study showed that especially the latter functional processes seem to be of particular relevance in situations of motor conflict induced through motor contagion (Spengler et al., 2009). Highly consistent with other neuroimaging studies (Amodio & Frith, 2006; Northoff et al., 2006), these functions, such as mental state attribution and self-related processing, activated the medial prefrontal cortex (mPFC), the same region that also yielded a key activation in the imitation-inhibition task (Fig. 1B, Brass, Ruby & Spengler, 2009). Self-referential processing concerns stimuli that are experienced as strongly related to one’s own person (Kelley et al., 2002; Northoff et al., 2006) and are common to the distinct concepts of self in different domains, for example in autobiographical memory, self-description, self-evaluation or self-reflection (Northoff & Bermpohl, 2004). Similarly, the mPFC is thought to be involved during attribution of intentional mental states, including emotions, thoughts, attitudes, and beliefs, to both oneself and other persons (Frith & Frith, 2003; Gilbert et al., 2006; Fig. 1B). Most importantly, the fMRI study by Spengler et al., 2009 demonstrated, that a lower interference effect, meaning that participants managed to enforce their own intention more efficiently and thus exhibited less motor mimicry, was associated with higher activation in mPFC. This indicates that interindividual differences in the mechanisms of processing information about the self, led to a higher ability to execute their own motor intention under a condition of motor contagion. Accordingly the arising question is if not only stable interindividual differences, as in traits related to chronically heightened or lowered self-focus and self-reflection (Fenigstein, Scheier & Buss, 1975), can enhance action control of motor contagion, but also if it is be possible to improve such action control processes by experimentally inducing changes in self-focus.

Evidence from social psychology is consistent with the idea that self-focus can enhance short or long-term goals, intentions or norms (Dijksterhuis & Bargh, 2001). The theory of objective self-awareness (Duval & Wicklund, 1972) has proposed that humans possess the unique capacity to become the object of one’s own attention. This internally directed self-awareness is assumed to activate inner standards and provoke a comparison with the actual behaviour these standards (Duval & Wicklund, 1972; Silvia & Duval, 2001), but also important goals and motivations and the current state or behavior should be more salient and accessible under self-focus (Carver & Scheier, 1981, 1990). Numerous experiments have shown that objective self-awareness can be induced by placing subjects in front of a mirror, camera or audience and by playing recordings of one's own voice (Wicklund & Duval, 1981). For example, self-awareness induced by the 'mirror-manipulation' reduces automatic behaviour (e.g. the effects of stereotypes) by rendering different action possibilities more salient (Dijksterhuis & van Knippenberg, 2000). Self-focus can be directed to all self-aspects, including one's current mental states (e.g., attitudes, intentions, emotions). Self-awareness also includes knowing that we are the same person across time, that we are the author of our thoughts and actions, and that we are distinct from the environment (Kircher & David, 2003). Ingram (1990) defined self-focus as "an awareness of self-referent, internally generated information that stands in contrast to an awareness of externally generated information derived through sensory receptors" (pg. 156). Although self-focus can generally activate all facets of one's own self, it has been proposed that the dominant dimension of the current situation or context will automatically determine the transfer of the self-focus on this particular aspect (Duval & Wicklund, 1972). Applied to situations of motoric conflict, self-awareness processes could be pivotal to reinforce current internally produced action intentions against distracting, externally triggered action representations and might therefore modulate the degree of displayed automatic motor mimicry.

In line with this idea, two recent studies, one in a naturalistic and one in an experimental setting, have shown that social attitudes can modulate motor contagion

(Leighton et al., 2009; van Baaren et al., 2003). In these between-subject studies one group of participants were primed before the experiment in a sentence completion task, with either pro-social attitudes (e.g. words such as friend, cooperate, together), or with anti-social attitudes (e.g. independent, single, enemy). Both studies yielded more motor mimicry in the pro-social group compared to the anti-socially primed participants. One possible explanation of this effect might be that anti-social attitudes promote a higher degree of self-focus in the participants, as this condition probably is more self-related than the pro-social condition, which in contrast refers rather to shared experiences with other agents. Heightened self-awareness may enhance action control mechanisms by raising the focus on internally generated action representations and possible concurrent inhibition of externally induced action representations.

Our study thus aimed to explicitly test this hypothesis with a more conclusive within-subject design, as so far, most relevant studies from social psychology on objective self-awareness have employed between-subject designs (). To carefully investigate the effect of self-focus on action control mechanisms during motor contagion, we used an established experimental paradigm, the above-mentioned imitation-inhibition task, which as been employed in several previous studies (Brass et al., 2000, 2005; Spengler & Brass, 2009). In this task participants have to perform either an index- or middle-finger lifting movement, while concurrently perceiving either congruent or incongruent finger movements (Fig.1A). The advantage of this paradigm lies in its heightened sensitivity to produce interference effects, as it is a choice reaction-time task, and that both inhibitory (i.e. the amount of inhibition of the contagious incongruent movement) and facilitatory effects (i.e. the degree of motor contagion from the congruent condition) on motor mimicry can be differentiated. This is of particular relevance for the present study, as our hypothesis of enhanced action-control mechanisms under self-focus predicts, first, minimized motor mimicry, expressed in a reduced interference effect, under the self-focus condition, and, second, more specifically that the smaller interference effect should be caused by enhanced performance under motoric conflict, meaning shorter reaction times in incongruent trials rather then longer reaction times on congruent trials. To induce heightened self-focus, we used a well-established method of non-instructed mirror self-observation the first experiment, which has yielded effects of increased self-awareness in numerous experiments from social psychology (). Participants performed the imitation-inhibition task, either while concurrently seeing themselves in a mirror opposite to themselves (self-focus condition), or they instead performed the task in front of a black board (no self-focus condition). If self-awareness enhances action control mechanism, needed to resist motor mimicry, then a decreased interference effect, caused by increased inhibitory processes in incongruent trails, should be observed. The second experiment aimed at replicating the results of the first study, but this time with another, novel method of self-focus induction. In this experiment subjects again completed the imitation-inhibition task, but this time the self-focus was elicited by a self-referential task, namely judging evaluative statements (e.g. “Leipzig is a pleasant town.”) in the self-focus block. In the control condition the presented sentences rather necessitated retrieval from semantic memory (“Leipzig is the capital of Germany.”). In neuroimaging studies this self-referential task has reliably elicited activation of the mPFC (Zysset et al., 2002), the cortical area most commonly related to the processing of self-relevant information (Northoff & Bermpohl 2004). The rationale for this procedure was to test whether another class of self-referential stimuli, namely more abstract, lingualistically mediated self-knowledge, can enhance the same action control mechanisms resolving conflict of motor representations.

EXPERIMENT 1

Participants

Nineteen volunteers (female, mean age years, range) participated in the experiment. All participants were right-handed and had normal or corrected-to-normal vision. The experiment was undertaken with the understanding and written consent of each subject and in compliance with national legislation and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki).

Procedure

After arrival participant received a written instruction of the imitation-inhibition task and were given 20 practice trials. Participants performed one block of the imitation-inhibition task under self focus and one block without self-focus. In the self-focus condition two mirrors were put on the left and right side of the monitor, so that participants could see their face and upper part of their body in the mirror. They were however instructed that the mirror was irrelevant for the experiment and that participants should focus on the experiment. After the first block, subjects received a short break of approximately 5 min, in which they were led outside the testing room to decrease possible effects of the preceding self-focus conditions. Under the no self-focus condition the mirrors were turned around with the non-reflective side facing the subjects. The block order was fully counterbalanced across subjects. After the experiments subjects were fully debriefed about the aim of the experiment and were paid for their participation.

Imitation-inhibition task

In the imitation-inhibition task (Brass et al., 2000), participants had to lift their index or middle finger in response to a number (1 = lift index finger, 2 = lift middle finger), whilst viewing simultaneously congruent or incongruent finger movements on a computer screen (Fig. 1A). As in congruent trials, the video-taped hand executed an identical finger movement to the instructed movement, the participants were not required to distinguish their intended action from the observed action. Their response was therefore a *quasi-imitative reaction* with regard to the observed movement, which is normally indicated by faster reaction times on congruent trials (Brass et al., 2000). Contrary, in incongruent trials the instructed movement differed from the observed movement, which introduces an imitative tendency to execute the observed movement. This necessitates subjects to enforce the intended movement against the observed action, reflected in longer reaction times on incongruent trials (Brass et al., 2000). The required response on incongruent trials reflects therefore a *non-imitative reaction* with regard to the perceived movement. The experiment consisted of incongruent trials and congruent trials which were presented randomly. The video sequence began with a frame showing the hand, which mirrored the right hand of the subject, in resting position for 650 ms. Two frames lasting 34 ms then showed the finger movement (congruent and incongruent trials). The video sequence finished with the finger in the end position (650 ms). The imperative stimulus was presented with the onset of the movement. The screen remained blank between trials for 2 s. Responses were recorded with custom-built keypad, which used light sensors to detect finger lifting movements of the index and middle finger of the subjects' right hand.

Results and discussion

A repeated-measurement ANOVA of the reaction time data with the factors self-focus (mirror, no mirror) and the factor condition (incongruent, congruent) revealed a main effect of condition ($F(1,18) = 133.7$, $p < 0.001$), no main effect of self-focus ($F(1.18) = 0.7$, $p > 0.4$) and, as predicted, a significant interaction effect self-focus by condition ($F(1,18) = 4,8$, $p < 0.4$) (Fig. 3B), thus showing a reduced interference effect in the imitation-inhibition task (Fig. 3A). Planned t-tests indicated that this interaction effect was rather driven by faster reaction times in incongruent trials under self-focus condition ($t(18) = 1.5$, $p < 0.5$, one-tailed) than reaction times on the congruent condition ($t(18) = -0,2$), $p <0.4$, one-tailed). A second ANOVA did not reveal a significant interaction for error rates ($F(1,18) = 0.008$, $p < 0.9$).

Our first experiment revealed that a self-focus manipulation can successfully minimize motor mimicry. This experiment used an established method of self-focus enhancement, the 'mirror manipulation', which uses physical stimuli (perception of one's own face) to induce self-related processing. Experiment 2 aimed to replicate these findings by using a different method of heightening self-focus, namely by using verbal stimuli which have to be evaluated and thus call onto processes of self-knowledge and -valuation. The second study also used a better suited control condition than Experiment

1, namely a semantic memory task, to control for additional processes not related to self-focus induction.

EXPERIMENT 2

Participants

Sixteen volunteers (female, mean age years, range) participated in the experiment. All participants were right-handed and had normal or corrected-to-normal vision. Experiment was undertaken with the understanding and written consent of each subject and in compliance with national legislation and the Declaration of Helsinki.

Procedure

After arrival participants received a written instruction of the imitation-inhibition task and the self-referential task and were informed that they had to perform both tasks in alternation. They were then given 20 practice trials. Participants performed one block of the imitation-inhibition task under self focus and one block without self-focus (Fig. 3). In the self-focus condition participants performed alternating trials of the self-referential task and the imitation-inhibition task. In the no self-focus condition a semantic memory task as a control condition was presented in alternation with the imitation-inhibition trials. After the first block, subjects received a short break of approximately 5 min, in which they were led outside the testing room to decrease possible effects of preceding self-focus conditions. The block order was fully counterbalanced across subjects. After the experiments subjects were fully debriefed about the aim of the experiment and were paid for their participation.

Imitation-inhibition task

The same task and stimuli were used as in Experiment 1. The task consisted of 30 congruent and 30 incongruent trials which were presented randomly. The trials of the imitation-inhibition task were presented intermixed with the trials of the self-referential task. The intertask-interval was 2 s.

Self-referential task

In order to tap processes related to self-knowledge (i.e. the ability to differentiate self from other objects and recognize attributes and preferences of oneself (Amodio & Frith, 2006)), we used a replication of an evaluative task developed by Zysset and colleagues (2002). Evaluative judgments are a special type of judgment, in which the internal scale is related to the person's value system (preferences, norms, aesthetic values, etc.). In contrast to memory retrieval in general, many evaluative judgments are self-referential in that they refer to the subjects "narrative" self (Gallagher, 2000). In the evaluative conditions participants had to read sentences and had to decide whether they agreed with this statement (e.g. "Leipzig is a pleasant town"). In order to isolate processes specific for self-related, evaluative judgments, we used semantic memory retrieval trials (e.g. "Leipzig is the capital of Germany.") as a control condition. For each experimental condition 60 sentences were randomly presented. Sentences have been carefully controlled for an equal distribution of yes- and no-responses and for difficulty in the memory condition (for further information on the stimulus material see Zysset et al., 2002). In each trial the sentence was presented for 2 s. Subjects were given 4 s after stimulus onset to respond by saying “yes” or “no” into a headset. We used verbal response to prevent interference with the motor response in the imitation-inhibition task. Participants were informed that their verbal responses were recorded to ensure their compliance with the instruction.

Results and discussion

Analysis of the reaction time data with a repeated-measurement ANOVA (factors self-focus (mirror, no mirror) and the factor condition (incongruent, congruent) revealed a main effect of condition ($F(1,15) = 50, 9$, $p < 0.001$), a main effect of self-focus ($F(1,15) = 8.2$, $p < 0.01$) and again a significant interaction ($F(1,15) = 5,3$, $p < 0.035$) (Fig. 4B) and thus again reduced interference in the self-focus block (Fig. 4A). Planned t-tests showed that this main effect of self-condition and the interaction effect were driven by faster reaction times in incongruent trials under self-focus condition compared to the no self-focus block ($t(16) = -3,1$, $p < 0.006$). The congruent condition did not significantly differ between the two blocks (self-focus, no self-focus) ($t(15) = -1,9$, $p < 0.07$). A second ANOVA did not reveal a significant interaction for error rates ($F(1,15) = 0.5$, $p < 0.4$).

By employing a different method of self-focus induction Experiment 2 thus corroborated the findings of Experiment 1, that self-focus leads to an enhancement of online action control mechanisms under motor contagion.

GENERAL DISCUSSION

Our present study combined recent findings from functional neuroimaging on the control of motor mimicry (Spengler et al., 2009; Brass et al., 2009) and well-established evidence from social psychology on self-awareness (Duval & Wicklund, 1972) to derive our current hypotheses. In particular, it was predicted that heightened self-focus should lead to an enhancement of action control mechanisms needed during motor contagion. Our findings from a within-subject design confirmed this idea by showing that the interference effect in the imitation-inhibition task was diminished under self-focus, driven especially through increased performance in trials with a conflict between own and observed action intention. Crucially, we were able to replicate these results in two experiments, which differed in the method of self-focus induction, ruling out alternative explanations due to a specific implementation of self-focus enhancement. Experiment 1 used the commonly used ‘mirror-manipulation’ to enhance self-focus by means of visual presentation of one’s own face, while Experiment 2 demonstrated that also abstract evaluative judgments call on self-reflective processes. This is in line with previous findings from functional neuroimaging, which have shown that a whole range of self-related stimuli across all functional domains- physical and psychological stimuli (e.g. facial and bodily information or emotional, mnemonic, verbal and conceptual stimuli) (Northoff et al., 2006)- can activate cortical midline structures, particularly the mPFC, which is dedicated to the processing of self-related information (Amodio & Frith, 2006). For example, mPFC has been recruited by seeing one’s own face (Kircher et al.,, 2001; Platek et al., 2003, 2004), or hearing one’s own name (Kampe et al., 2003), as well as by conceptual processing of self-knowledge, such as reflecting on our own personal characteristics (e.g. Zysset et al., 2002; Kelley et al., 2002). Consistently, our findings show that different self-related information can elicit self directed processing, but, more importantly, that self-focus can elicit functional mechanisms, which are pivotal for the enhancement of own intentions under motor contagion.

One intriguing, but still speculative, question is which functional mechanisms exactly mediate the influence of self-focus on the amount of overt motor mimicry, or on ‘mirroring’ responses, which show a close match between perceived stimulus and motor response, in general. Ideomotor theory proposes that the translation from visual stimuli to a corresponding motor representation in the observer occurs because actions are represented in the form of the sensory feedback they produce (Brass & Heyes, 2005) (Fig. 5). Thus, both intended and perceived movements subsequently activate the matching motor representation. Although this model at a first glance implies that the visuomotor translation operates automatically and thus produces an invariant motor output, several moderating factors may have an influence on the resulting behaviour.

Heyes and Bird (2008) suggested that changes in exhibiting mirroring behavior could be due to several moderating factors. First, it may be influenced through input factors, variables, which affect stimulus processing, such as attention to the perceived stimulus or stimulus salience; second, sensorimotor experience and the individual’s history of learning affecting the translation from sensory to motor representations, and third, output factors, including top-down processes, such as task instructions, intentions or knowledge. These output factors would influence whether the activation of a motor representation is inhibited or expressed in overt behavior (right side, Fig. 5). Ideomotor theory assumes that actions become bound to their sensory consequences through associative learning and, as we did not modulate such learning in the present study, the influence of sensorimotor experience may be in this case disregarded. Concerning input factors, these moderators might influence the processing of the input stimuli by increasing or decreasing attention towards the observed body movements. In turn, this would also affect the amount of motor mimicry exhibited by the participants through more or less activation of the corresponding sensory and motor representation. It might be argued that in Experiment 1, attention towards the movement stimulus was diminished during the mirror manipulation and thereby caused the decrease of the inference effect in the self-focus condition. This would be expected if the perception of one’s own mirror image distracts the attention of the participants from the monitor. Such a distractor effect should result in general slower reaction times in the self-focus block, as the time to identify the imperative stimulus would also be prolonged. However, we did not find any main effect of self-focus on reaction times in Experiment 1, and, if at all, general RTs in the self-focus condition were faster compared to the control condition in Experiment 2. Furthermore, if it was the case that self-focus lowers the processing of body movements by focusing attention onto the imperative stimulus then congruent trials, as a measure of the facilitation induced by the perception of the to-be-executed movement, should have slower reaction times under the self-focus compared to the no self-focus condition. But such an effect could not be found in both experiments, as the reaction times in the congruent condition were either similar or rather faster in the self-block. In line with the findings of Leighton et al. (2009), where likewise no evidence was found for an attentional modulation on motor mimicry effects, these results argue against the impact of input factors on the current diminished interference effects under self-focus. Therefore, output factors, comprising ‘top-down’ processing, seem to be the most likely candidate for the observed modulation of motor mimicry effects. Top-down control, with the prefrontal cortex as the most likely source of these signals, is related to long-term cognitive strategies and goals, and can temporarily enhance or decrease processing of related information (Miller & D’Esposito, 2005). This is consistent with our initial hypothesis that self-related processing in mPFC may modulate motor mimicry responses in motor cortices. More specifically, there may be two possible ways how increased self-focus may influence the motor representation stage - through an activating or an inhibitory route (left side in Fig. 5). Our model proposes that heightened self-awareness may enhance the intention coding the desired movement, and in turn, then either activate the motor representation of this movement (green line, this would in fact be mediated by a prior enhancement of the corresponding sensory representation), or by inhibiting the motor representation corresponding to the perceived, opposite movement (red line). Although there is so far no firm evidence, which would speak clearly for one of those two alternatives, preliminary findings would rather support the inhibitory route. Two recent neuroimaging studies suggest that the mPFC, hosting the proposed top-down influences of self-focus, was negatively correlated with areas implicated in mirroring either emotional or motor input, when this input was undesired for the task at hand (Cheng et al., 2007; Spengler et al., 2009). Additionally, it may be possible that self-related processing in mPFC might modulate the motor representation level, even when no own intentions exist, a hypothesis which has not been explicitly tested so far, although it was shown that during pure action observation, self-attribution of actions diminished the excitability of the primary motor cortex (Schuetz-Bosbach et al., 2004).

Additionally, it may be possible that the effect of heightened self-focus on motor mimicry is mediated by the evocation of emotions. It has been shown that increased self-awareness leads to negative affect, through the realization of the discrepancy between the current and desired state, regarding for example one's goals or norms (Duval & Wicklund, 1972), especially in depressive populations (). Moreover, it has been shown that also negative affect enhances self-focus (Mor & Winquist, 2002; Wood, Saltzberg, & Goldsamt, 1990). Furthermore, theories on emotional processing have suggested that negative emotions, for example, the experience of sadness either in oneself or through the perception of conspecifics, leads to a general inhibition of behaviour, which may serve an adaptive survival function to possibly avoid the occurrence of similar negative events (Killagoe et al., 2004; Potts et al., 1989). Thus, negative emotions may lead in general to an inhibition of the motor representation stage, suppressing automatically activated motor responses, to prevent further behavior evoking negative outcomes and emotions. In contrast, positive affect may be related to increased unintentional motor mimicry of observed behavior to increase the likelihood of positive and rewarding consequences. Interestingly, the reverse effect has been shown, namely that being imitated by someone else leds to positive mood and the activation reward-related circuits (Chartrand & Bargh, 1999, Kuehn et al., subm.).

In summary, our findings have relevance to theories conceptualizing possible influence factors on motor contagion processes and on online action control mechanisms to reduce automatic imitation effects. Here, we show that, possibly top-down mediated, moderating factors can alter mirroring responses during motor contagion. Showing that a modulation of motor mimicry is possible by imposing self-focus conditions may also be of importance in changing automatic motor mimicry effects in natural settings and everyday situations. This may have implications for changing undesired or detrimental effects of automatic imitative behaviour, such as heightened aggressive behaviour after expose to community or media violence (Guerra at al., 2002,; Huesmann et al., 1983) or increased imitation of alcohol consumption in social situations (Larsen et al., 2009). Enhanced focus on one's own goals and intentions and a belief in one's own capacity to freely choose actions (Baumeister et al., 2009) might help counteract predominant imitation-driven behavior.

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REFERENCES

FIGURE CAPTIONS

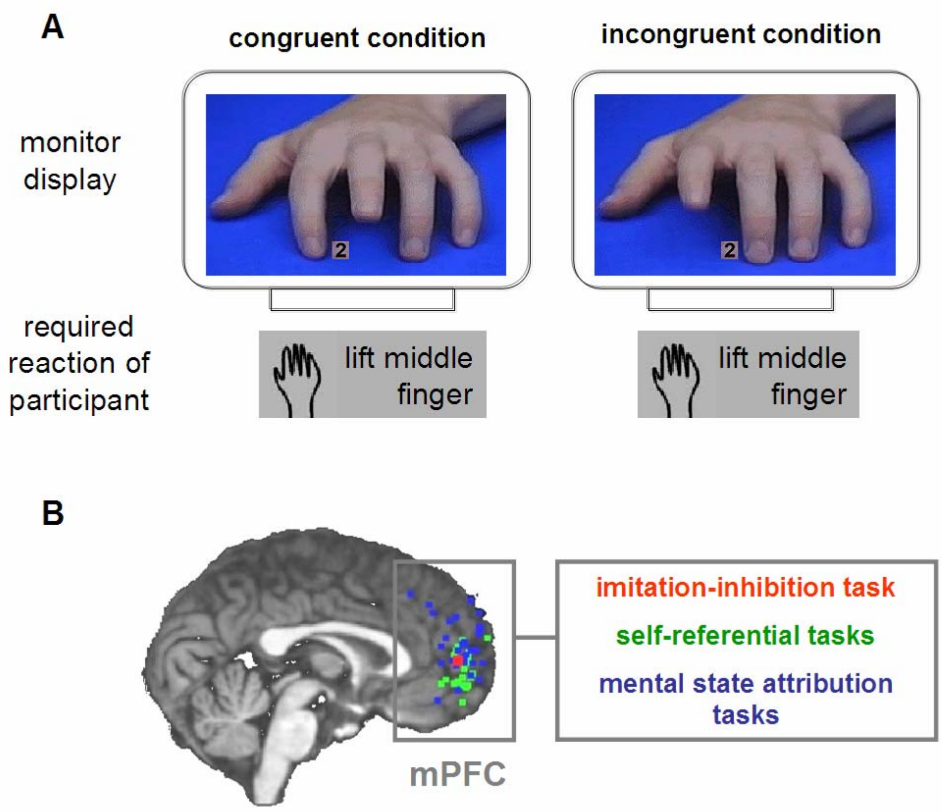
Figure 1. A) During the imitation-inhibition task participants have to respond to a number on the monitor (1 or 2) by lifting their index- or middle finger. Concurrently, either the same movement (congruent condition) or the opposite movement is presented (incongruent condition). Displayed are two example stimuli for both conditions and the required response of the participant. B) Meta-analysis of functional neuroimaging studies (taken from Brass, Ruby & Spengler, 2009). The imitation-inhibition task (red dot) activates a similar region in the medial prefrontal cortex (mPFC), as self-referential (green) and mentalizing tasks (blue points).

Figure 2. Experiment 1: A) Mean interference effect for reaction times (incongruent minus congruent trials) and standard error of the mean for the self-focus and no self-focus block. B) Reaction times for in the incongruent and congruent condition with and without self-focus.

Figure 3. Example of a trial sequence of the self-focus and no self-focus block in experiment 2.

Figure 4. Experiment 2: A) Mean interference effect for reaction times (incongruent minus congruent trials) and standard error of the mean for the self-focus and no self-focus block. B) Reaction times for in the incongruent (continuous line) and congruent condition (dotted line) with and without self-focus.

Figure 5. A schematic model of ideomotor action control and possible moderating factors, see text for explanation.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incongruent condition
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2
required reaction of participant
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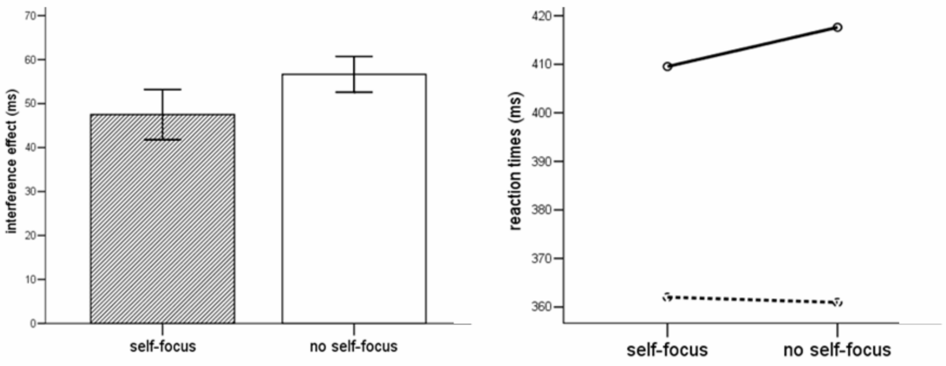
lift middle finger
B
imitation-inhibition task
self-referential tasks
mental state attribution tasks
mPFC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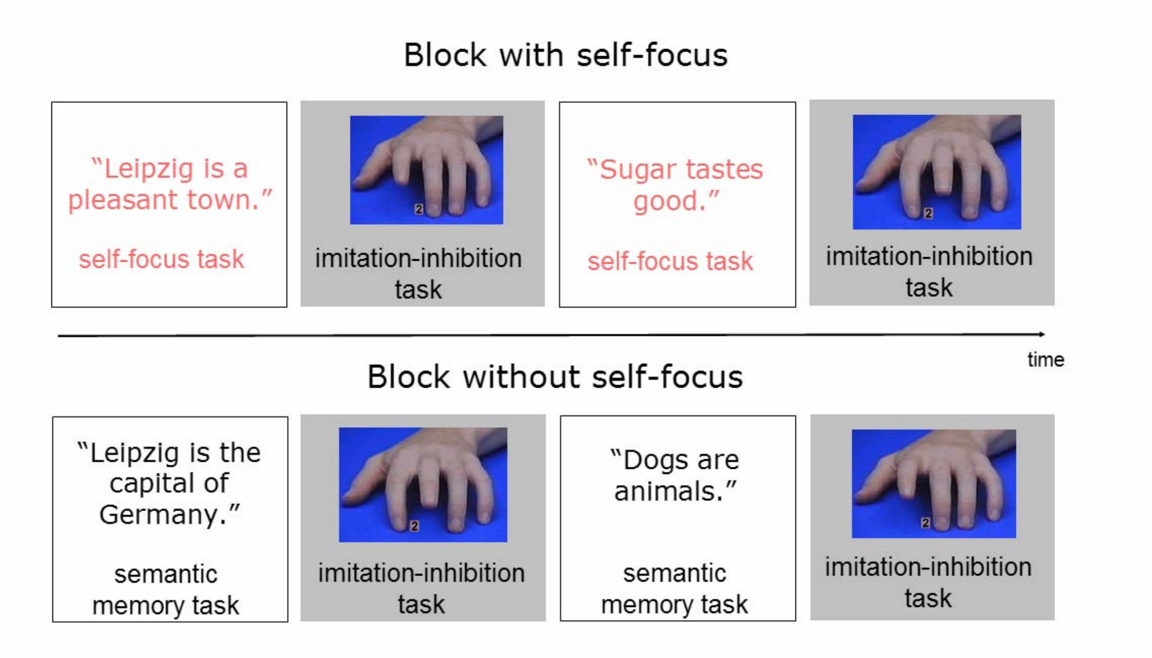
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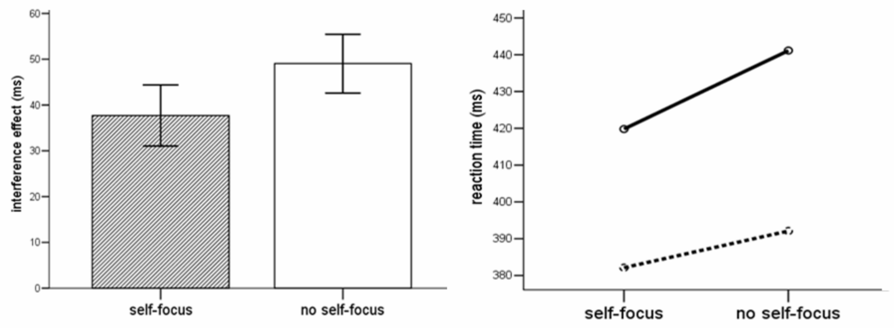
self-focus task
2
imitation-inhibition task
"Sugar tastes good."
self-focus task
2
imitation-inhibition task
time
Block without self-focus
"Leipzig is the capital of Germany."
semantic memory task
2
imitation-inhibition task
"Dogs are animals."
semantic memory task
2
imitation-inhibition task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reaction time (ms)
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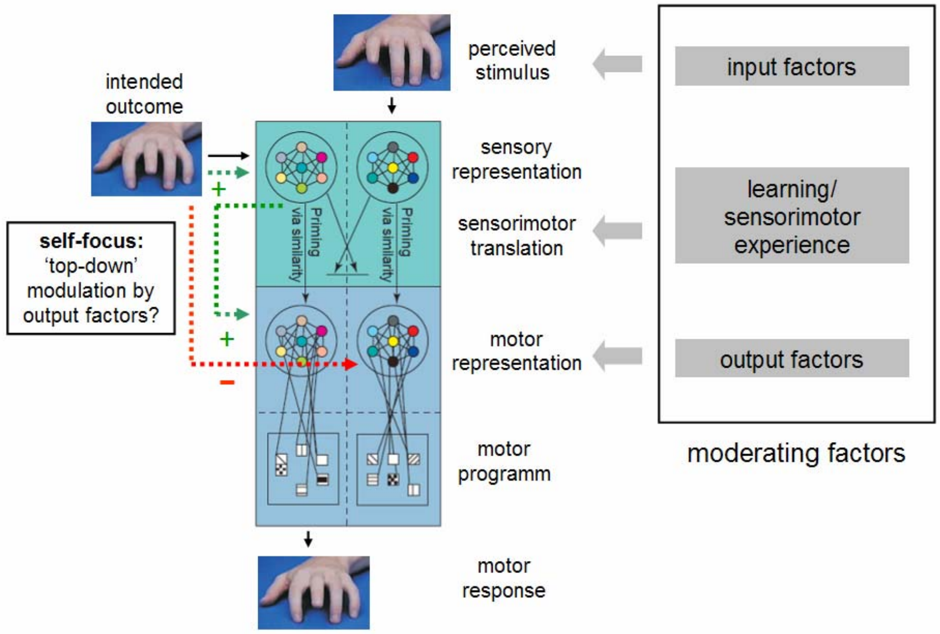
intended outcome
perceived stimulus
sensory representation
Priming via similarity
Priming via similarity
sensorimotor translation
self-focus: 'top-down' modulation by output factors?
+
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motor representation
motor programm
motor response
input factors
learning/ sensorimotor experience
output factors
moderating factors