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Self-related primes reduce congruency effects in the Stroop task

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Raw data and analysis scripts for all experiments reported can be found on the OSF: https://osf.io/gdqze/?view_only=3c1f5e79ab4f4e268f64840cf3891cbb (this link will be replaced with the link to the public project after peer-review).

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Abstract

Theoretical accounts of self-representation assume a privileged role for information that is linked to the self and suggest that self-relevant stimuli capture attention in a seemingly obligatory manner. However, attention is not only biased towards self-relevant information, but self-relevant information might also tune attention more broadly, for instance, by engaging cognitive control processes that regulate allocation of attention. Indeed, research in social, clinical and developmental sciences predicts a close link between a cognitive representation of the self and cognitive control processes. The present research is concerned with such a possible signalling function of the self to recruit cognitive control and tested predictions that follow from this view using the well-known Stroop task. Participants identified the print color of words. Self-reference was manipulated such that a prime was presented before or together with a Stroop word that comprised of either a possessive pronoun (e.g., MY GREEN) or a definite/indefinite article as control (e.g., THE/ A GREEN). Results of three experiments (N_{total} = 137) showed that self-reference priming reduced the congruency effect in the Stroop task relative to control conditions. This finding is incompatible with an attentional bias account assuming that self-relevant distractors always impair performance, but rather suggests that stimuli relevant to the self can facilitate cognitive control processes.

[208 words] [250 words]

Key words: Stroop; Self-reference; Cognitive control; Self-relevant pronouns

Introduction

The ability to focus attention on selective parts of the environment is a critical aspect of controlled behavior. Although we are very good at blocking of irrelevant information most of the time, there are cases in which this efficient filtering fails. Perhaps the most prominent example is the “cocktail party” effect in which the own name of participants is registered even though this information is unattended (Moray, 1959). This effect illustrates that highly salient information of personal relevance, like one´s own name, captures attention in a seemingly obligatory manner (Sui & Humphreys, 2015). However, attention is not only biased towards self-relevant information, but self-relevant information might also tune attention more broadly, for instance, by engaging cognitive control processes that regulate allocation of attention. Indeed, research in social, clinical and developmental sciences predicts a close link between a cognitive representation of the self and cognitive control processes (e.g., Bandura, 1997; Baumeister, Heatherton, & Tice, 1994; Miskowiak et al., 2018). The present research is concerned with this signalling function of the self to prime cognitive control that allows for goal-directed actions.

The attentional bias view

According for the attentional bias account, attention is drawn towards self-referential information irrespective whether this information is relevant or irrelevant for the task. Support for this view comes from a wide range of different tasks providing evidence that self-referential stimuli compared to control stimuli enhance detection (Bargh, 1982; Sui, He, & Humphreys, 2012; Schäfer, Frings, & Wentura, 2016; Bundesen, Kyllingsbaek, Houmann, & Jensen, 1997; Schäfer & Frings, 2015; Pfister, Pohl, Kiesel, & Kunde, 2012), facilitate stimulus-response translation (Golubicki & Macrae, 2021; Janczyk et al., 2019; Schäfer et al., 2020; Stein et al., 2016) and foster memory (Symons & Johnson, 1977; Klein & Loftus, 1988 Cunningham, Turk, Macdonald, & Macrae, 2008; Klein & Kihlstrom, 1986; Rogers, Kuiper, & Kirker, 1977), if they are task-relevant. Furthermore, the self-advantage for task-relevant information has been linked to reduced activity in brain regions typically associated with cognitive control functions (i.e., dorsolateral prefrontal cortex) (Sui, Rotshtein, & Humphreys, 2013).

Conversely, if stimuli are task-irrelevant (as in the “cocktail party” effect described above), the privileged status of self-reference impairs performance in the actual task (Shapiro, Caldwell, & Sorensen, 1997; Welford & Morrison, 1980; Arnell, Shapiro, & Sorensen, 1999; Kawahara, & Yamada, 2004 Frings, 2006; for the cocktail party effect, see Wood & Cowan, 1995a,b, Mack & Rock, 1998) suggesting that self-referential stimuli direct attention away from the primary task. Based on these and other findings, it has been suggested that “self-processing […] runs counter to the function of the executive control when the self-related information is irrelevant to task requirements and individual goals” (Sui & Rotshtein, 2019, p. 148).

The priming of control view

However, self-referential stimuli might also modulate attentional selectivity more broadly. For instance, neurophysiological studies observed activation in similar brain areas during tasks that recruit cognitive control and tasks that involve self-referential processing (e.g., Abraham, 2013; Ogawa, Masaki, Yamazaki, & Sommer, 2011). More direct evidence comes from studies that manipulated personal relevance and found increased control functions (e.g., error processing, see Koban, Pourtois, Vocat, & Vuilleumier, 2010; Steinhauser & Kiesel, 2011). Kleiman and colleagues reported enhanced sustained control for stimuli related to food or social outgroups only if food consumption or stereotyping had personal relevance for the participants (Kleiman et al., 2014; Kleiman, Trope, & Amodio, 2016; see also Nunes, Casey, Egner, Hare, & Hirsch, 2005). They concluded that “personal relevance may be an important modulator of control adjustment" (Kleiman et al., 2014, p. 498). This suggests that self-referential processing might modulate attentional selectivity by *increasing* cognitive control. Indeed, a rich research tradition emphasized the close link between successful regulation of behaviour and the mental representation of the self in terms of personal values, motives and desires (Baumeister et al., 1994; Fujita, 2011) and it has been suggested that self-referential processing in particular might be one way to regulate emotions and behaviour (see Northoff, 2005). Furthermore, mounting evidence suggests that self-referential processing can also affect later stage of information processing (e.g., Janczyk et al., 2019; Schäfer et al., 2020; Stein et al., 2016). Together, these different lines of research converge on the assumption that information related to the self might be beneficial for control in general, for instance by increasing the motivation to exert control (see also Northoff, 2005; Eitam & Higgins, 2010). The present research aims to test this idea in more detail.

Probing cognitive control of response-interference

A useful way to assess cognitive control is by means of so-called conflict tasks, like the Color-Stroop task. Here, responding to the relevant dimension of the task (i.e., naming the ink color of a word) is affected by the irrelevant task dimension (i.e., the semantic meaning of the carrier color word). The congruency effect [CE] refers to the difference in color naming between congruent (*RED* printed in red) and incongruent (RED printed in blue) combinations and provides a measure of conflict between representations afforded by task-relevant and irrelevant dimensions. Typically, changes in the size of the CE are taken as an index of conflict resolution due to increased cognitive control. This specific focus on conflict tasks is motivated by theoretical models of cognitive control that describe conflict as a central problem arising from simultaneous activation of multiple representations (see Musslick & Cohen, 2021, for an overview). Consequently, many models evoked dedicated mechanisms to resolve conflict have been central to explain adaptive behavior (e.g., Allport, 1987; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miller & Cohen, 2001; Norman & Shallice, 1986).

It should be emphasized that conflict in the Color-Stroop task must not be confused with unspecific disruption in Stroop-like tasks (for a detailed account, see Algom, Chajut, & Levy, 2004). To illustrate this point, consider Experiment 1 of a study by Gronau, Cohen and Ben-Shakhar (2003) that compared identification of print colors for carrier words that either had a reference to the self (e.g., own name) or had no such reference (e.g., an unknown name). Although this task is superficially similar to the Color-Stroop task, it is structurally different in important aspects. Most relevant for the present discussion, identifying the print-color of one’s own name or identifying the print-color of a control name is neither congruent or incongruent, because there is no overlap between responses afforded by colors and responses afforded by names (in fact, participant did not respond to names at all in this study). Thus, the slowing effect for self-referential names relative to control names demonstrated unspecific disruption, and not a conflict between specific responses, because there was no structural overlap between names and colors which would constitute congruent or incongruent combinations. Research using such ´Stroop-like´ tasks demonstrate the attention grabbing power of self-referential stimuli; however, these tasks do not allow inferences about cognitive control functions (i.e., conflict resolution). Therefore, the present research employs a classic colour Stroop task to infer changes in cognitive control.

Do self-referential stimuli bias cognitive control?

Going beyond previous demonstrations that self-referential stimuli bias the orientation of attention, the present study investigated whether self-referential stimuli modulate cognitive or executive control. While the attentional bias hypothesis holds that irrelevant self-referential stimuli direct attention away from the primary task, the priming of control hypothesis submits that irrelevant referential stimuli should cue increased control exertion. This juxtaposition of the attentional bias and the control priming account brings to mind the famous dichotomy between bottom-up and top-down attentional control (see e.g., Connor, Egeth, & Yantis, 2004). The attentional bias account resembles classical ´bottom-up´ effects which can impair goal-directed processing due to the presentation of an irrelevant stimulus (e.g., Posner, 1980). In contrast, the priming of control account conforms with ´top-down´ effects, showing that task-irrelevant stimuli can trigger cognitive control and therefore facilitate goal-directed behavior (e.g., Botvinick et al., 2001). Similarly, both accounts can also be described in Peterson and Posner influential distinction between different attentional networks. While the attentional bias account maps to the orienting network, the control priming account refers to the executive control network (Peterson & Posner, 2012). For a test of these competing hypothesis, we use the Color-Stroop task and ask whether presentation of self-referential stimuli modulates conflict resolution, as indicated by the size of the CE. Please see figure 2, upper panel, for a graphical illustration of both hypothesis.

There are two basic ways how self-referential stimuli could be integrated into the color-Stroop task. First, self-referential information could be linked to the relevant task dimension (i.e, naming of the ink color). For this setup, the control priming hypothesis and the attentional bias hypothesis make the same predictions (albeit for different reasons): CEs should be reduced for self-reference compared to a control condition. The control priming account predicts reduced CEs because control favors relevant information over irrelevant information; the attentional bias account predicts reduced CEs because self-relevant information draws attention towards the relevant dimension.

Alternatively, self-referential information could be linked to the irrelevant dimension (i.e., to word reading). For this task setup, the control priming hypothesis and the attentional bias hypothesis make different predictions: The control priming account again expects a reduced CE, because control should favor relevant over irrelevant information. In contrast, the attentional bias view predicts an increased CE, because self-relevant information draws attention towards the irrelevant dimension, increasing response-interference. For a decision between both hypotheses, the present research manipulated self-relevance selectively for the irrelevant dimension.

In the color-word Stroop task, the irrelevant dimension refers to the semantic meaning of the carrier color word. A way to associate the semantic meaning of a word like “GREEN” with the self is the use of possessive pronouns. Previous studies showed that nouns accompanied by a possessive pronoun (e.g., “MY HOUSE”) led to faster identification and better memory performance for these nouns relative to nouns paired with infinite articles (“A HOUSE”) or with articles that refer to another person (“HIS HOUSE”) (Shi, Zhou, Han, & Liu, 2011; Zhou et al., 2010; Herbert, Herbert, Ethofer, & Pauli, 2011). Similarly, Walla et al. (2007, 2008) as well as Herbert et al. (2011) reported that nouns accompanied by the possessive pronoun “my” elicit stronger neural responses during early processing stages (already 250 ms after stimulus onset) than nouns paired with infinite articles (Walla, Greiner, Duregger, Deecke, & Thurner, 2007; Walla, Duregger, Greiner, Thurner, & Ehrenberger, 2008; Herbert et al., 2011; for behavioral evidence, see Herbert, Hesse, & Wildgruber, 2018). In addition, Herbert, Pauli, & Herbert (2011) demonstrated preferential processing of self-referential pronoun-noun pairs compared to control stimuli when pronouns and nouns were presented sequentially as prime-target pairs.

The present research

Based on this research, we reasoned that the presentation of a self-referential possessive pronoun together with a color word (e.g., “MY GREEN”) should lead to increased activation of the semantic meaning of the color word relative to color words accompanied by a non-self-referential definite or indefinite article (e.g., “THE GREEN” or “A GREEN”). Our main question was how self-referential primes modulate CEs. According to the attentional bias hypothesis, CEs should be increased for the self-reference condition relative to controls because the increased activation of the irrelevant information should interfere with the selection of the goal-directed naming response in incongruent trials. According to the priming of control hypothesis, CEs should be decreased for the self-reference condition relative to control, because self-relevance improves cognitive control over the task-irrelevant response tendency. Figure 1 provides an overview of the design.

Experiment 1

In the first experiment, we tested whether self-reference increased or decreased the size of the congruency effect. We collected RTs and errors rates while participants performed a manual Color-Stroop task. Participants had to indicate one out of four print colors (yellow, blue, green, red) of color words with a left or right keypress. To manipulate self-reference, a prime word (printed in white) was presented before the color word which could be either the possessive pronoun “MEIN” (german for “my”) or the indefinite article “EIN” (german for “a”). Both prime words are orthographically highly similar in German. Participants were explicitly instructed to ignore the meaning of the colored word. They were also told that shortly before the colored word, another word would be presented which is irrelevant for this task. A key question was whether a self-reference prime would amplify or mitigate interference of irrelevant semantic information.

[Figure 1 should be placed around here]

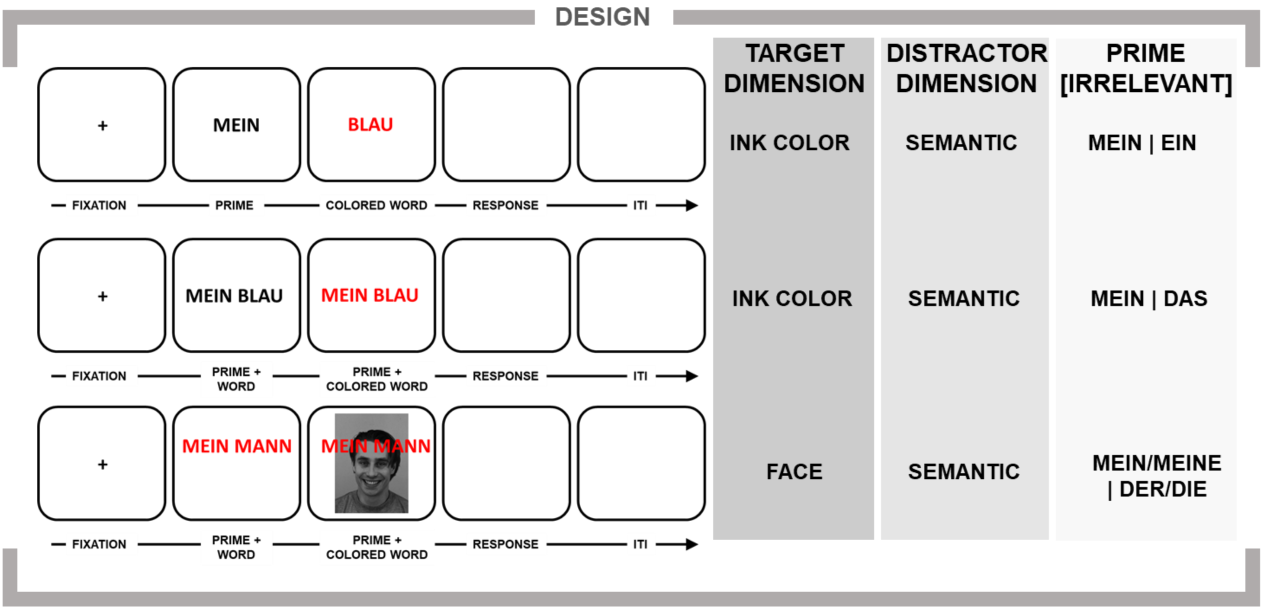

Figure 1. Left side: Trial sequence of Experiments 1-3 (from top to bottom), see text for presentation duration and details. Pictures in Exp. 3 were taken from the Karolinska Directed Emotional Faces database (BM28HAS; see methods of Exp. 3 a list of all included picture stimuli). For better visibility, black and white colors are interchanged in the figure. Right side: Target and distractor dimension and prime condition for each Experiment. Participants were instructed to responded with left and right key presses to the target dimension (Exp. 1 & 2: ink color of colored words; Exp. Gender of the face). The distractor dimension had to be ignored, but predicted the correct response in 50% (Exp. 1 & 2) or 66% /Exp. 3) of the cases. The prime was nominally irrelevant and always presented in the same dimension as the distractor (i.e., as a word).

Method

Raw data and analysis scripts for all experiments reported can be found on the OSF: https://osf.io/gdqze/?view_only=3c1f5e79ab4f4e268f64840cf3891cbb (this link will be replaced with the link to the public project after peer-review). Outlier criteria were identical for all experiments and determined a-priori (based on our previous research with response-interference task), as were the analysis plans and hypothesis. The experiments were not preregistered.

Participants

We used G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) for power calculations with $\alpha = .05$ and $1-\beta = .8$ as input parameter for a two-sided paired-sample t-test (interaction effects were estimated with difference scores). Two considerations determined the sample size of experiment 1 and 2 for which data collection overlapped temporally. First, we aimed to replicate a Stroop effect which often produces large effects. For instance, the ´Many Labs 3´ study (Ebersole et al., 2019) reported a Stroop effect with d = 0.91. We estimated that 12 participants are required to detect a statistically significant effect. Second, we aimed to find an effect of self-referential stimuli. Previous research that reported a processing advantage of self-referential pronouns over control words (Herbert et al., 2010; 2011; 2018; Shi et al., 2011; Walla et al., 2007, 2008; Zhou et al., 2010) reported no effect sizes and we also could not retrieve relevant t-statistics or means and standard deviations of conditions to compute effect sizes. The largest sample in this set of studies was N = 22. Regarding the novel interaction hypothesis in the present research, we were not aware of any published study that addressed the influence of self-referential pronouns on the CE. Together, these considerations only provided a lower limit for our sample size and, for practical reasons, we continued data collection depending on availability of lab space. A sensitivity analysis showed that the obtained sample sizes in Exp. 1 and 2 were sufficient to detect a medium sized effect [d = 0.48 - 0.56].

Twenty-seven participants (23 women, 18–44 years) participated in exchange for course credit or 7€. Participants were naive regarding the purpose of the experiment. Data of one experiment could not be analyzed due to a programming error. Exclusion criteria were identical for all three experiments: Participants with more than 50 % error were excluded due to random performance in the 2-alternative-forced-choice task. From the remaining sample, all participants with a mean error rate above 3 SDs were treated as outliers. No participant had to be excluded according to these criteria in Experiment 1.

Stimuli

Stimuli were presented with E-Prime (2.0.8.90a, Schneider, Eschman, & Zuccolotto, 2002) on a 17-inch monitor. German color words for blue, red, green and yellow (“BLAU”, “ROT”, GRÜN”,” GELB”) were presented on a black background. The carrier word was printed in either blue, red, green or yellow color (standard E-Prime color palette). Primes consisted of the possessive pronoun “MEIN” (German for ´my´) and the indefinite article “EIN” (German for ´a´) and were printed in white. All words were written in capital letters in 48 point Segoe UI. Participants responded on a QWERTZ keyboard with the keys “D” and “L” marked with white patches.

Procedure

A trial started with the presentation of a fixation cross for 512 ms, followed by the prime for 608 ms. Then the color word was shown (without the prime) for 304 ms, followed by a blank screen until response registration. In case of anticipated (RT < 100 ms), incorrect, or late response (RT >2000 ms) an error message appeared for 1008 ms. The next trial started after a variable intertrial interval of 256-512 ms. Participants were instructed to classify the ink color of the word as quickly and as accurately as possible. Furthermore, instructions stated that shortly before the colored word, another word would be present which is not relevant for the task and can be ignored.

The experiment consisted of 10 consecutive blocks of 48 trials. In each trial block, the color words were presented 6 times with a congruent and 6 times with an incongruent ink color. Congruent and incongruent color words were presented equally often in the self-reference (possessive prime word) and the control condition (indefinite article prime word). The assignment of the four ink colours to the two response keys was counterbalanced across participants according to a Latin square. After each block, participants received feedback about their mean reaction times and error rate.

Results

Due to a programming error, 1/48 trials per block presented an incorrect pronoun “SEIN” (“his”) before an incongruent stimulus (in total 10 trials). These trials were excluded from the analysis. Trials with erroneous responses (8.6%) and post-error trials (7.8%) were discarded from the RT and error analyses. In addition, RTs were removed that exceeded more than 3 SDs from the individual cell mean for each condition (1.3%). For an overview of mean reaction times and error rates separately for each condition and experiment, see table 1.

Reaction Times. A repeated-measures ANOVA with the factors *Congruency* (congruent, incongruent) and *Prime* (self-reference, control) yielded a significant main effect of *Congruency*, $F(1, 26) = 25.32$, $p < .001$, $\eta_p^2 = .493$. Responses were faster in congruent trials ($M = 459$ ms) compared to incongruent trials ($M = 476$ ms). The main effect of *Prime* was not significant, $F(1, 26) = 1.72$, $p = .201$, $\eta_p^2 = .062$. The interaction between *Congruency* and *Prime* was significant, $F(1, 26) =4.38$, $p = .042$, $\eta_p^2 = .150$.The congruency effect was reduced for self-reference condition (Δ=13ms), $t(26) =3.29$, $p = .003$, $dz = 0.63$, compared to the control condition (Δ=20 ms), $t(26) =5.35$, $p < .001$, $dz = 1.03$ (see figure 2, lower panel).

Error Rates. An analogous ANOVA of the error rates showed only a significant main effect of *congruency*, $F(1, 26) = 5.44$, $p = .028$, $\eta_p^2 = .173$. Participants made more errors in incongruent trials ($M = 9.4$ %) compared to congruent trials ($M = 7.9$ %). Neither the main effect of *prime* (F<1) nor the interaction effect was significant, $F(1, 26) = 3.04$, $p = .093$, $\eta_p^2 = .105$.

Discussion

We observed typical congruency effects indicating interference by the irrelevant semantic information in the Color-Stroop task. More importantly, congruency effects differed between prime conditions: the color Stroop effect was smaller in the self-relevance priming condition with a personal possession prime word (“MY”) compared to the control condition with a definite article prime word (“A”). Critically, this finding supports the control priming hypothesis that self-referential stimuli improve conflict resolution.

[Table 1 should be placed around here]

Table 1. Response latencies (in ms) and error rates (in %) for Experiment 1 – 3. Standard errors in parenthesis.

Trial type	Experiment 1		Experiment 2		Experiment 3	
	Latency (ms)	Error rate (%)	Latency (ms)	Error rate (%)	Latency (ms)	Error rate (%)
Con **|** self-reference **|** SOA 1	462 (10)	7.6 (0.8)	452 (11)	7.8 (0.7)	453 (6)	7.3 (0.6)
Inc **|** self-reference **|** SOA 1	476 (12)	9.7 (0.8)	468 (13)	8.2 (0.9)	497 (7)	15.1 (1.0)
Con **|** control **|** SOA 1	456 (10)	8.3 (0.9)	451 (11)	7.8 (0.7)	441 (6)	6.2 (0.6)
Inc **|** control **|** SOA 1	477 (12)	9.1 (0.9)	472 (13)	9.9 (1.0)	500 (7)	16.1 (1.1)
Con **|** self-reference **|** SOA 2			441 (12)	5.3 (0.8)		
Inc **|** self-reference **|** SOA 2			486 (13)	10.2 (1.3)		
Con **|** control **|** SOA 2			435 (11)	5.0 (0.6)		
Inc **|** control **|** SOA 2			495 (13)	11.1 (1.1)		
ΔCE **|** self-reference	self	2.1	30	2.5	44	7.8
ΔCE **|** control	21	0.8	40	4.1	60	9.9

Note. Con = congruent, Inc = incongruent; ΔCE = Congruency Effect; ´self-reference´ and ´control´ refer to the prime; SOA 1 (Exp. 1 = 608 ms; Exp. 2 = 16 ms; Exp. 3 = 160 ms), SOA 2 (Exp. 2 = 160 ms; no SOA manipulation in Exp. 1 & 3).

[Figure 2 should be placed around here]

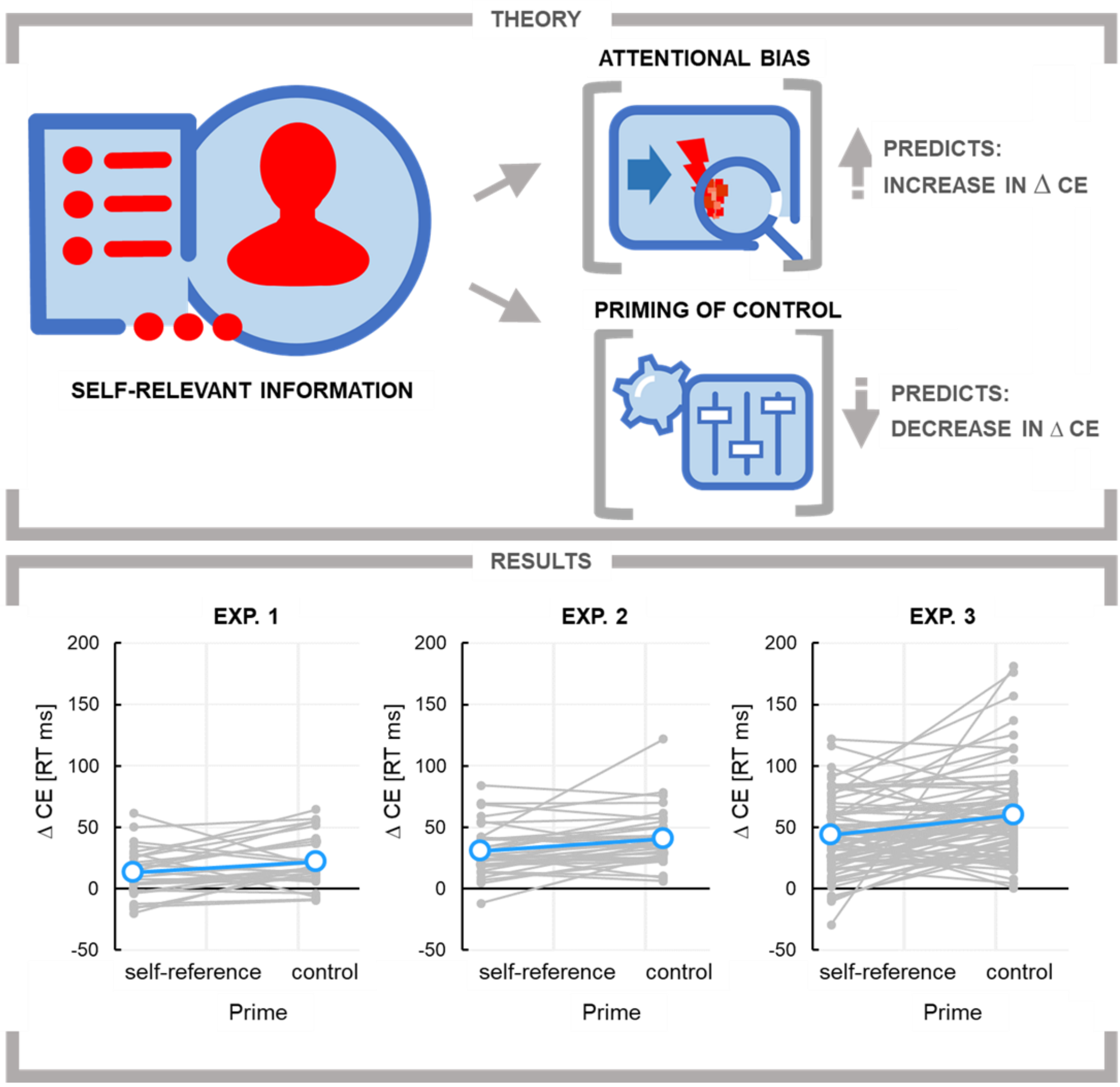

Figure 2. Upper panel: Theoretical predictions. According to the attentional bias hypothesis, CEs should be increased, because self-relevant information draws more attention to the irrelevant distractor dimension of the Stroop task. According to the priming of control hypothesis, CEs should be decreased, because self-relevant information improves cognitive in the Stroop task. Lower panel: Result for Experiment 1-3 show the congruency effect (CE = incongruent -congruent) for RTs separately for both prime conditions (self-reference vs. control). Grey lines indicate individual data of participants, blue lines indicate the mean.

Experiment 2

Experiment 1 had two limitations. First, the indefinite article “EIN” (german for “a) was used as a prime in the control condition. Yet, in written German language color nouns are more frequently used in combination with definite than indefinite articles[1]. To rule out that the self-referential priming effect observed in Experiment 1 is not an artifact of an atypical article-noun combination, Experiment 2 used the definite article “DAS” (german for “the”) as a new control condition. Second, Experiment 1 presented prime and target sequentially. Sequential presentation of primes and targets engages temporal attention, because primes predict the relative onset of target stimuli (see e.g., Dignath, Schiltenwolf, Kiesel, & Hazeltine, 2021). Major theoretical accounts of control in the Stroop task, however, describe control as a reconfiguration of stimulus-response features (Botvinick et al., 2001; Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2009). Experiment 2 therefore sought to replicate the impact of self-referential stimuli on CEs using simultaneous presentation of prime and target which eliminates any selection based on temporal order of events. Against this background, Experiment 2 provides a further test of the priming of control hypothesis with the major goal to replicate reduced CEs for self-referential primes compared to control primes.

An additional, more exploratory objective of Experiment 2 was to test whether manipulations known to affect interference in the color Stroop task also affect the self-referential priming effect. This could serve as a diagnostic test whether the control-enhancing effect of self-referential primes follows the rules of Stroop interference in general (see Algom et al., 2004 for a related discussion). In the color Stroop task, conflict increases with stronger activation of the distractor dimension; one method that

[1] Based on a Google-Ngram© search for the German corpus (2012) for all color words used in this study either with the finite or infite article (e.g., “ein Blau, das Blau”).

strengthens the distractor information is the advance presentation of the distractor relative to the target information; for instance, by presenting the color word initially in a neutral color (e.g., white, which was not mapped to any response), prior to the relevant print color (Erikson & Schultz, 1979; see also Flower, 1980; Wendt, Kiesel, Geringswald, Purmann & Fischer, 2014). In analogy to this manipulation, Experiment 2 used either short or long advance presentation of distractor (i.e., irrelevant word meaning) information to manipulate conflict strength. In line with previous research, we hypothesized that CEs should be larger with long relative to short advance distractor presentations. Most relevant to the present research question, we predicted that self-referential priming should counteract such increased conflict effects due to enhanced control over distractor information. Specifically, because we presented primes always simultaneously with distractors, longer advance presentation should not only increase conflict (irrespective of prime condition), but also provide more time to upregulate control, i.e., to suppress irrelevant distractor information in the self-referential priming condition. Statistically, this should produce a three-way interaction, with stronger reduction of congruency effect for the self-referential prime relative to the control conditions for longer compared to shorter advance presentation.

Methods

Participants

For sample size considerations, see Exp. 1. Thirty-six participants (24 women, 19–56 years) who did not participate in Experiment 1 participated in exchange for course credit or 7€. No participants had to be excluded due to the outlier criterion.

Stimuli and Procedure

Stimuli and material were identical to Experiment 1, except for the control condition prime which was the definite article “DAS” (German for ´the´).

Procedure

Before the start of the Stroop task, participants indicated their current mood state on a visual analogue scale (0 [very bad] to 100 [very good]) using the computer mouse. A Stroop trial started with the presentation of a fixation cross for 512 ms, followed by a combination of the prime and the color word (e.g., “MEIN BLAU”). Both words were printed in white on black background at a central position and had a duration of either 16 ms or 160 ms. We will refer to this as short and long stimulus-onset-asynchronies (SOA) between irrelevant and relevant color information in the Stroop task. The prime word and the color word were then colored for 304 ms, followed by a blank screen presented until response registration. In case of anticipated (RT < 100 ms), incorrect, or late response (RT >2000 ms) an error message appeared for 1008 ms. The next trial started after a variable intertrial interval of 256-512 ms.

The experiment consisted of 10 consecutive blocks of 48 trials for the 16 ms SOA and 10 consecutive blocks of 48 trials for the 160 ms SOA. The order of the SOA conditions was counterbalanced across participants. In each trial block, each color word was presented 6 times with a congruent and 6 times with an incongruent combination of ink color. Congruent and incongruent color words were presented equally often with the prime “MEIN” (engl., “MY”) in the self-reference condition or “DAS” (engl., “THE”) in the control condition. The assignment of the four colors to the two response keys was counterbalanced across participants according to a Latin square. After each block, participants received feedback about their mean reaction times and error rate.

Results

Trials with erroneous responses (8.4%) and post-error trials (7.3%) were discarded from the RT and error analyses. In addition, RTs were removed that exceeded more than 3 SDs from the individual cell mean for each condition (1.3%).

Participants' mood was slightly pleasant (M = 65.50, SD = 18.38). Exploratory analysis showed a marginal significant correlation between this self-report measure and the relevant interaction (see below) between prime condition and congruency effects (r (36) = -.294; *p* = .082; however, this correlation was not robust when eliminating one outlier (> 4SD, remaining sample: *r* (35) = .036, p =.835).

Reaction Times. A repeated-measures ANOVA with the factors *Congruency* (congruent, incongruent), *SOA* (16 vs. 160 ms), and *Prime* (self-reference, control) yielded a significant main effect of *Congruency*, $F(1, 35) = 129.08$, $p < .001$, $\eta_p^2 = .787$. Responses were faster in congruent trials (*M* = 445 ms) compared to incongruent trials (*M* = 480 ms). Main effects of *SOA* and *Prime* were not significant, *Fs*<1. The interaction between *Congruency* and *SOA* was significant, $F(1, 35) = 55.78$, $p < .001$, $\eta_p^2 = .614$ The congruency effect was smaller for the short SOA condition (Δ=18ms, $t(35) = 6.88$, $p < .001$, $d = 1.14$ relative to the long SOA condition (Δ=53ms, , $t(35) = 10.99$, $p < .001$, $d = 1.83$). Furthermore, the interaction between *Congruency* and *Prime* was significant, $F(1, 35) = 9.78$, $p = .004$, $\eta_p^2 = .218$. Most relevant, the congruency effect was reduced for the self-referential prime (Δ=30 ms, $t(35) = 9.36$, $p < .001$, $d = 1.56$) compared to the control condition (Δ= 40 ms, $t(35) = 10.96$, $p < .001$, $d = 1.82$). The three-way interaction effect was not significant, $F(1, 35) = 3.49$, $p = .07$, $\eta_p^2 = .091$. Descriptively, the reduction of the congruency effect by self-referential information relative to control was larger for the longer SOA condition (Δeffect= -15 ms) compared to the shorter SOA condition (Δeffect= -4 ms), see figure 2 (lower panel).

Error Rates. An analogous ANOVA of the error rates revealed a significant main effect of *Congruency*, $F(1, 35) = 17.67$, $p < .001$, $\eta_p^2 = .336$. Participants made more errors in incongruent trials (*M* = 9.9 %) compared to congruent trials (*M* = 6.5 %). The main effects of *SOA* and *Prime* did not reach significance, $F(1, 35) = 1.73$, $p = .196$, $\eta_p^2 = .047$ and $F(1, 35) = 3.29$, $p = .078$, $\eta_p^2 = .086$. The interaction between

Congruency and *SOA* was significant, $F(1, 35) = 30.10$, $p < .001$, $\eta_p^2 = .462$. The congruency effect was smaller for the short SOA condition (Δ=1.1%), $t(35) = 1.86$, $p = .071$, $d = 0.31$, relative to the long SOA condition (Δ=5.5%), $t(35) = 5.18$, $p < .001$, $d = 0.86$. Furthermore, the interaction between *Congruency* and *Prime* was significant, $F(1, 35) = 5.88$, $p = .021$, $\eta_p^2 = .144$. The congruency effect was reduced for self-referential prime (Δ=2.5%, $t(35) = 2.796$, $p = .008$, $d = 0.36$) compared to the control condition (Δ=4.1%, $t(35) = 5.34$, $p < .001$, $d = 0.89$). The interaction between *SOA* and *prime* and the three-way interaction effect were not significant with *F*s <1.

Discussion

Experiment 2 replicated a smaller CE with self-referential primes compared to control. This supports the hypothesis that self-relevant information can boost cognitive control and conflict resolution. Furthermore, Experiment 2 ruled out potential confounds with infrequent article-noun combinations in the control condition. The simultaneous presentation of prime and carrier words also controlled for effects of temporal attention, suggesting that self-referential priming did not enhance control due to better temporal predictability. This is important, because the theoretical models describes control in the Stroop tasks by reconfiguration of stimulus feature-based attention (and not temporal attention).

Advance presentation of distractor information (i.e., word meaning) and primes produced expected results with larger CEs for earlier onset of distractor-relative to target-information. However, the predicted three-way interaction failed to reach significance; descriptively, self-referential primes presented together with distractor-information seemed to counteract the increase in conflict, which is in line with our reasoning and could indicate that both activation due to advance distractor presentation and suppression of irrelevant responses due advance prime presentation accrues over time.

Experiment 3

Experiment 3 was a high-powered, conceptual replication with the objective to corroborate that self-referential primes reduce CEs in the Stroop task. To generalize the self-referential priming effect to other stimulus material, we used a gender version of the Stroop task that required identification of the gender of faces while ignoring verbal gender labels displayed across the faces (e.g., the word “MANN”, German for “man”, superimposed on the face of a female person) (for a similar task setup see Egner, Etkin, Gale, & Hirsch, 2008). Furthermore, a potential caveat of Experiment 1 and 2 could be that the identity of the prime (e.g., MEIN vs. EIN) repeated or changed across consecutive trials. Research has shown that repetition of even irrelevant stimuli can act as a retrieval cue, recollecting previous responses and abstract attentional sets from memory (Frings et al., 2020). Although it seems not clear how such transient memory could explain the self-referential priming effect, repetition and alternation of primes can complicate the interpretation of conflict effects (e.g., Hommel, Proctor, & Vu, 2004). Experiment 3 addressed this potential limitation by holding prime repetition constant and presented self-referential primes and control primes in separate blocks of trials.

Method

Participants

Based on the averaged effect sizes of the interaction between congruency and prime in Experiment 1 and 2, a minimum sample size of N = 53 participants would be required to achieve a power of 1-β = .8 for a conceptual replication. Seventy-seven volunteers (63 women, 18–53 years) who did not participate in Experiment 1 or 2 participated in exchange for course credit. Data from two participants with extremely high error rates (> 3 SDs; *M* > 28%; rest of the sample *M* = 9.8%, *SD* =5.3%) were excluded.

Stimuli

A greyscale photographic stimulus depicting a happy or angry female or male face taken from the Karolinska Directed Emotional Faces set (AF01ANS, AF01HAS, AF02ANS, AF02HAS, AF17ANS, AF17HAS, AF22ANS, AF22HAS, BM03ANS, BM03HAS, BM10ANS, BM10HAS, BM25ANS, BM25HAS, BM28ANS, BM28HAS; Lundqvist, Flykt, & Öhman, 1998) was presented on a black background. The photographs subtended 17.08° of visual angle in width and 22.26° height, measured from a viewing distance of 50 cm. For the gender Stroop task, the words “FRAU” and “MANN” (German for “female” and “male”) were presented. These words were presented together with the possessive pronoun “MEIN” or “MEINE” (German for “my”) in the self-reference condition or with the definite article “DER” or “DIE” (German for “THE”) in the control condition. The words were written in red capital letters in 48 point Segoe UI font, and they superimposed either the upper or lower part of the face (location of distractor information changed randomly across trials). Participants’ responded on a QWERTZ keyboard with the keys “I” and “D” marked with green patches.

Procedure

Participants first rated the current mood state and the concentration level on visual analogue scales (0 [very bad] to 100 [very good]) using the computer mouse. A gender Stroop trial started with the presentation of a fixation cross for 512 ms. Since Experiment 2 showed larger self-referential priming with extended advance presentations of distractors and primes, we presented the irrelevant prime-gender label word combination 160 ms before the face that was presented with the superimposed gender word for 304 ms. A blank screen was presented until response registration. In case of anticipated (RT < 100 ms), incorrect, or late response (RT > 2000 ms) an error message appeared for 1008 ms. The next trial started after a variable intertrial interval of 256-512 ms. At the end of the session, participants again indicated the self-assessed concentration on a visual analogue scale and completed the short form of the Narcissistic Personality Inventory (NPI-15; Spangenberg et al., 2013), which was included for explorative reasons and is here only reported for completeness.

The experiment consisted of 4 consecutive blocks for each prime condition (e.g., self-reference, control). The order of self-reference and control conditions was counterbalanced across participants. Each block of trials consisted of 48 trials, with each of the 16 facial stimuli presented twice with a congruent and once with an incongruent distractor word, resulting in 32 congruent and 16 incongruent trials. We decided to present more congruent trials, since previous research has shown that this can increase overall CEs (e.g., Soutschek, Stelzel, Paschke, Walter, & Schubert, 2014). After each block, participants received feedback about their mean reaction times and error rate.

Results

Trials with erroneous responses (10.0 %) and post-error trials (8.3 %) were discarded from the RT and error analyses. In addition, RTs were removed that exceeded more than 3 SDs from the individual cell mean for each condition (1.3 %).

Participants reported positive mood at the start of the experiment (*M* = 64.07, *SD* = 18.67); they indicated higher concentration before (*M* = 52.78, *SD* = 19.34) than after the experiment (*M* = 41.91, *SD* = 19.78). Mean NPI scores were *M* = 6.82 (*SD* = 1.58), which is considerably below average rating in US undergraduates (*M* = 15.6, Raskin & Terry, 1988) . Exploratory analysis showed no significant correlation between these self-report measures and the relevant interaction between self-reference and congruency effects (smallest *p* = .138).

Reaction Times. A repeated-measures ANOVA[2] with the factors *Congruency* (congruent, incongruent) and *Prime* (self-reference, control) yielded a significant main effect of *Congruency*, $F(1, 74) = 265.45$, $p < .001$, $\eta_p^2 = .782$. Responses were faster in congruent trials (M = 447 ms) compared to incongruent trials (M = 499 ms). The main effect of *Prime* was not significant, $F<1$. The interaction between *Congruency* and *Prime* was significant, $F(1, 74) = 13.51$, $p < .001$, $\eta_p^2 = .154$. The congruency effect was reduced for self-relevant primes (Δ=44 ms, $t(75) = 12.86$, $p < .001$, $d = 1.48$ compared to the control primes (Δ=60 ms, $t(75) = 14.18$, $p < .001$, $d = 1.63$), , see figure 2 (lower panel).

Error Rates. An analogous ANOVA of the error rates revealed a significant main effect of *Congruency*, $F(1, 74) = 112.17$, $p < .001$, $\eta_p^2 = .603$. Participants made more errors in incongruent trials (M = 15.6 %) compared to congruent trials (M = 6.8 %). The main effect of *Prime* did not reached significance, $F<1$. The interaction between *Congruency* and *Prime* was significant, $F(1, 74) = 4.84$, $p = .031$, $\eta_p^2 = .061$. The congruency effect was reduced for self-relevant primes (Δ=7.78 %; $t(75) = 9.48$, $p < .001$, $d = 1.09$ compared to control primes (Δ=9.95 %, $t(75) = 9.03$, $p < .001$, $d = 1.04$).

Discussion

The results replicate the findings of Experiment 1 and 2 using a gender Stroop task. As in the previous experiments, congruency effects were reduced for self-referential primes relative to control primes. Furthermore, Experiment 3 used a blocked presentation of self-referential and control primes which eliminated potential memory-based carry-over effects across consecutive trials (see Frings et al., 2020). The block

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[2] An exploratory analysis that included the affective valence of the facial expression showed no effect of valence (negative vs. positive) on RTs; main effect and all interactions with valence, F<1.

design could also be interpreted as a strong test of the priming of control hypothesis, since recent research suggests that blocked presentation of self-relevant information reduces the self-advantage (see Golubickis & Macrae, 2021b).

General Discussion

The present study investigated whether processing of self-related information improves cognitive control. We used a Stroop task to assess the degree of conflict resolution as an indicator of cognitive control and manipulated self-related information by presenting possessive pronouns or definite/indefinite articles (control condition) as primes. Across three experiments, we found smaller congruency effects when the target was primed with a self-referential possessive pronoun (MY) compared to a control prime. This result was observed when primes were presented before (Exp. 1) and together (Exp. 2 & 3) with target words, the effect was robust across different control conditions and extended across different stimulus material and task protocols. Together, these findings suggest that self-relevant information acts as a cue to recruit more control and therefore helps to shield against interference from irrelevant information.

How do self-referential primes facilitate control?

The present research was set up to arbitrate between different functional accounts of self-related information processing. According to the priming of control hypothesis, self-relevant information should act as a cue to signal the need for increased control (i.e., self-relevance affects top-down processing). According to the attentional bias hypothesis, attention is directed more strongly to self-relevant information (i.e., self-relevance affects bottom-up processing). Based on these accounts, we derived opposing predictions for a Stroop task in which the distractor information became self-relevant by association with a possessive pronoun. For this task setup, the control priming view expected that CEs should be reduced due to an improved resolution of response conflict, whereas the attentional bias account proposed that CEs should be increased due to stronger impact of irrelevant distractor information. Although the results clearly supported the control priming hypothesis, we do not deny that self-relevant information can attract and hold attention. In fact, an increase in distractor activation could be one possible explanation for the hypothesized boost in control. Many models of cognitive control assume that the strength of distractor activation scales with the implementation of control (Botvinick et al., 2001; 2001; see also Grison & Strayer, 2001).

More specifically, increased activation of irrelevant information leads to stronger conflict. Since conflict acts as a learning signal to change attentional filtering, stronger conflict should trigger more control (Botvinick et al., 2001). Although initially formalized to account for control across consecutive trials, recent empirical research (Scherbaum, Fischer, Dshemuchadse, & Goschke, 2011; Kałamała, Ociepka, & Chuderski, 2020) and modelling work (Weichart, Turner, & Sederberg, 2020; see also Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004) suggest a similar control mechanisms for conflict resolution within a trial. Thus, the present findings are not incompatible with an attentional bias for self-referential stimuli; instead, we suggest that self-referential stimuli have different functional and behavioral consequences depending on the task. While these stimuli, when presented along with task-irrelevant information, impair performance in many tasks, (e.g., Alexopoulos et al., 2012; Röer, Bell, & Buchner, 2013), they facilitate performance in tasks that probe cognitive control with response-interference task like the Stroop used in the present research. While this explanation assumes that the locus of self-referential priming of control is due to early modulation of stimulus processing an alternative view assumes that self-relevance enhances cognitive control more directly by activating current task goals. This view dovetails with recent findings suggesting that some effects of self-relevance are due to central processing and changes in the stimulus-response translation (e.g., Golubickis & Macrae, 2021; Janczyk et al., 2019; Schäfer et al., 2020).

Other accounts for a self-referential priming of cognitive control refer to arousing, emotional, motivational or mnemonic effects of self-relevant information. We will address each of them in turn. Gronau et al. (2003) suggested self-referential stimuli like one´s own name elicit an orienting response which is associated with increased arousal. According to a recent model, arousal operates as a ´glue´, strengthening relevant stimuli and responses links that are needed for the resolution of the conflict resolution (Verguts & Notebaert, 2008). It has also been suggested that the experience of challenging task demands, such as response conflicts, elicits arousal (Inzlicht, Bartholow, & Hirsh, 2015). Based on this research literature, it can be speculated whether self-referential stimuli might have boosted control by increasing arousal. Indeed, a recent study by Landmann and van Steenbergen (2020) assessed the joint influence of irrelevant high arousal compared low arousal words in combination with possessive pronouns or control words. Overall, results showed that sustained control, across consecutive trials, was facilitated for high arousal words (see also Zheng et al., 2018; but see Dignath, Janczyk, & Eder, 2017) and in particular for conditions in which high arousal words were accompanied by self-referential pronouns. The present findings corroborate this observation for transient, within-trial control. Furthermore Landmann and van Steenbergen (2020) failed to find evidence that referential primes enhance control directly, i.e., irrespective of additional arousal stimuli. Going beyond this research, the present research established that self-referential primes facilitate control even in the absence of additional arousing stimulation. This points to a more general role of self-relevant processing for cognitive control processes.

A different perspective is suggested by theories postulating that control is driven by emotional responses (Dreisbach & Fischer, 2015; van Steenbergen, 2015; for a review, Dignath, Eder, Steinhauser, & Kiesel, 2020). Several studies support the idea that response conflict triggers a negative affective reaction, which increases control (see e.g., Berger, Mitschke, Dignath, Eder, & van Steenbergen, 2020; van Steenbergen, Band, Hommel, 2009). According to this account, self-referential primes could modulate emotional response to conflict in two ways. First, self-reference might increase emotional intensity more general. For instance, appraisal theories posit that personal relevance acts as a moderator, increasing emotional responses which are significant for the self (Scherer, 2001). Second, self-referential primes might change emotional responses to conflict more specifically. Research on ´hedonic contrasts´ suggests that, for instance, negative emotional responses are evaluated as more negative against the background of previous or simultaneous positive emotions (Eder & Dignath, 2014; Larsen & Norris, 2009) and evidence suggests that this generalizes to conflict-triggered affect. For instance, conflict resolution seemed to increase for task-irrelevant, positive stimuli, which has been interpreted to result from hedonic contrast. Importantly, studies reported consistently that self-referential primes, like the pronouns used in the present research, are evaluated generally more positive (e.g., Herbert et al., 2011). Thus, self-referential primes might have elicited positive affect, resulting in contrast-enhanced negative affect triggered by conflict and thereby increased control.

Furthermore, information relevant to the self has been linked to motivational enhancements, presumably because it can increase a person’s willingness to engage in effortful behavior (e.g., Eitam & Higgins, 2010; Lockwood et al., 2017). In the present research, self-referential primes could have increased task engagement, which facilitated cognitive control. In fact, analogous effects of motivation on control were reported by studies that manipulating rewards, showing that increased motivation can facilitates conflict resolution (see Dignath et al., 2020; Frömer Lin, Wolf, Inzlicht, & Shenhav, 2021; Krebs, Boehler, & Woldorff, 2010). Furthermore, mechanisms relevant for conflict-resolution in the Stroop task prime motivational responses of approach and avoidance, suggesting a close link between control and motivation (Dignath & Eder, 2015; Schouppe, De Houwer, Ridderinkhof, & Notebaert, 2012; Hengstler, Holland, van Steenbergen, & van Knippenberg, 2014).

Finally, it has been proposed that a more general mechanisms of self-relevance is to support the binding of stimuli and responses in episodic memory (Sui & Humphreys, 2015; Schäfer et al., 2020; 2019). Interestingly, research on cognitive control has shown that we form a memory of abstract control configurations together with other co-occurring stimuli and responses, which can be quickly reactivated by appropriate retrieval cues (e.g., Dignath et al., 2019; Egner, 2014; Frings et al., 2020). It is tempting to speculate that reduced congruency effects for self-referential primes in the present research might reflect a modulatory impact of self-relevance on the binding and retrieval of cognitive control operations in episodic memory.

Limitations of the present research

In the Stroop tasks, conflict arises due to multiple factors (for reviews, see Banich, 2019; Parris et al., 2021). For instance, an incongruent trial causes semantic conflict (sometimes also called stimulus or information conflict), because the print color of a carrier word mismatches with the semantic meaning. In addition, if both colors are mapped to different responses, semantic conflict is combined response conflict. Furthermore, the dominate tendency to read words produces an additional task conflict between the instructed task to name the ink color and the automatic task to read the word (see Goldfarb & Henik, 2007). Unlike semantic and response conflict, task conflict affects both incongruent and congruent trials. All three types of conflict possibly contributed to congruency effects in the present study. One way to dissociate semantic and response conflict is a mapping manipulation that links four color to only two responses, creating trials that comprise of semantic and response conflict and trials that evoke only semantic conflict, because both print color and color meaning are mapped to the same response key (de Houwer, 2003). Although it was not the goal of the present research, the design of Experiment 1 and 2 allows to test such a dissociation. Upon reviewer request, the supplement presents an analysis showing that the modulatory influence of self-referential primes is not restricted to either type of conflict in the present data sets. Clearly, these post-hoc analysis do not rule out that multiple types of conflict could differ in their sensitivity to self-referential priming. Instead, we believe that future research should directly address this question by apriori planned manipulations (e.g., mapping variations and inclusion of neutral trials, see de Houwer, 2003; Goldfarb & Henik, 2007) and measurements (e.g., pupil diamenter, see Ronen & Henik, 2019) that allow a dissociation of various conflict types.

Just as congruency effects in the Stroop task comprise of different conflict types, it has been suggested that cognitive control relies on multiple mechanisms to resolve conflict (for a reviews, see Egner, 2008; Schuch et al., 2019). For instance, while the original conflict monitoring proposal emphasized the role of conflict during incongruent trials for control adaptation, subsequent work provided also evidence for critical role of congruent trials. First, it has been demonstrated that conflict does not generally vary with congruency level (Yeung, Botvinick, & Cohen), possibly because also congruent trials can cause conflict and control adaptation (e.g., Schlaghecken & Martini, 2012; Lamers & Roelofs, 2011; Compton et al., 2012). Indeed, this perspective is in line with numerous studies showing that previous conflict facilitated performance on congruent trials, but at the same time also impaired performance on congruent trials. Similarly, in the present research self-referential primes reduced the congruency effect by a combined facilitation of RT and error rates during incongruent trials and an impairment during congruent trials. These effects can be readily explained by assuming that self-referential primes increase control by strengthening the currently activated task-set, resulting in the amplification of the relevant dimension and a relative suppression of the irrelevant dimension. As a consequence, control reduces costs due to irrelevant information on incongruent trials, but it also reduces the faciliatory effect on congruent trials. Again, the present research was not designed to arbitrate between different control strategies and our design allowed for multiple way to adjust control (e.g., due to feature-based attention in Exp. 1-3; temporal attention in Exp. 2 and 3; spatial attention in Exp. 3). Future work could aim at isolating specific control mechanisms to better understand how self-referential primes enhance control.

Self-relevant stimuli like one´s own name or face are often highly overlearned and therefore confound effects of self-reference with familiarity (e.g., Prentice, 1990). Although the personal pronouns used in the present research were overall less frequent than the control words, we acknowledge that familiarity was not controlled for in our experiments. One way to address this problem is to create new, arbitrary associations between stimulus feature and self-relevance (see Sui, He, & Humphreys, 2012). A similar approach could be instructive for the present research program, for instance, by pairing specific colors with self-relevant information in a preceding acquisition phase, before the impact of self-relevant colors is probed in a color Stroop task as in the present experiments.

Summary

The current results show that self-referential primes facilitate control. How this boost in control is implemented on the process level is an important question for future research. For instance, research on affective disorders like depression or personality disorders found specific impairments in both, the processing of self-relevant information and in cognitive control (Davis, 1979; Miskowiak et al., 2018). The present research links both constructs in the search for a better understanding of the (mal)functioning of ´self-control´.

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