CONFLICTS AS AVERSIVE SIGNALS

Investigations on the Affective Valence of Conflict Stimuli

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DANKSAGUNG

“Angenehm sind die erledigten Arbeiten.“ (Cicero)

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PREFACE

This cumulative thesis presents three studies that investigated the affective valence of conflicts in information processing. All three studies have been published in peer-reviewed journals over the last three years. They are reproduced in their last accepted pre-print version with permission from the publishers. A short overview of the studies can be found on page six, the contributions of the co-authors of these studies are shown on page seven. The studies' three separate reference lists have been included into one bibliography at the end of the thesis, starting on page eighty-eight. The numbering of the experiments, tables, references and figures has been adjusted to fit the thesis as a whole. Otherwise, the manuscripts have not been changed.

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ABSTRACT

According to a recent theory by Matthew Botvinick (2007), conflicts in information processing are aversive. This assumption, its boundaries and its functionality, have been examined in three studies. **STUDY 1** tested if the conflict priming effect as found by Dreisbach and Fischer (2012a) can be reproduced with a different dependent variable, offering more clear-cut evidence for conflict aversiveness. Participants had to judge the valence of neutral German words or Chinese pictographs after being primed by conflict or non-conflict Stroop primes in two experiments. Results show that priming with conflict stimuli increases the frequency of negative judgments, thus giving unequivocal evidence for the aversiveness of conflicts. **STUDY 2** was designed to test the time characteristics of the conflict priming effect. In three experiments, the results show that conflict priming is present already with a SOA of 200 ms, highlighting the similarity between conflicts and other aversive stimuli. Furthermore, Study 2 showed a reverse priming effect for a SOA of 800 ms with continued prime presentation, maybe due to processes of affective counter-regulation. **STUDY 3** investigated whether it is the aversiveness of conflict stimuli that motivates conflict adaptation. In two separate experiments, subjects participated in two response conflict tasks, a color version of the Eriksen Flanker task and a manual version of the Stroop task. Here, the stimuli’s perceptual fluency (i.e., the ease of processing) was manipulated in short blocks of ten trials length. Disfluency (reduced figure-ground contrast) is associated with the experience of negative affect. Results showed that increasing the general stimulus aversiveness by adding disfluency eliminated conflict adaptation instead of increasing it. The results of the three studies are discussed in the light of current emotion and cognitive control research.

CONTRIBUTIONS

STUDY 1	***Conflicts as Aversive Signals – Conflict Priming Increases Negative Judgment for Neutral Targets***
Study idea	Gesine Dreisbach
Study design	Julia Pastötter
Data acquisition	Verena Dierlmeier, Hannah Wörther
Statistical analysis	Julia Pastötter
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STUDY 2	***The Time Course of the Aversive Conflict Signal***
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STUDY 3	***The Influence of Negative Stimulus Features on Conflict Adaptation: Evidence from Fluency of Processing***
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Study supervision	Gesine Dreisbach

PART I

INTRODUCTION

COGNITIVE CONTROL - AN OVERVIEW

‚Cognitive control‘ is an umbrella term used for a series of different cognitive processes which are often also referred to as ‘executive functions’: the flexible (re-) configuration of behavioral dispositions, the stimulus-independent selection of behavior, the maintenance and shielding of goals, the suppression of habitual reactions, the suppression of competing motivational tendencies or emotional impulses, the planning of actions, the coordination of multiple goals and, with special interest to the present thesis, the monitoring of conflicts and errors (cf. Goschke, 2002). Although these processes might seem quite heterogeneous at first glance (and the degree of their independence has yet to be resolved completely; cf. Goschke, 2003; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), it is these processes‘ common purpose that unites them: to optimize performance in such a way that an organism’s goals can be achieved.

Imagine, for example, you are on a diet and have to grocery shop. Your goal is to lose weight and to achieve this, you have to dismiss high caloric food from your menu and eat healthier, low caloric meals for some time. As your desire for sweets would conflict with your desire to lose weight, it would be best to avoid the sweets aisle when navigating your way through the supermarket. That is, going through the supermarket, you have to *monitor* for potential threats to your goal and shield it from them by *adjusting your behavior accordingly*. However, avoidance is only one way cognitive control functions may tune your behavior to fulfill goal attainment. In fact, cognitive control is what renders the behavior of humans highly flexible, adjusting it exactly to the specific situation at hand. To stay with the supermarket example, the row of sweets next to the supermarket checkout may present a situation of inevitable threat to your goal. Here, (spatial) avoidance is not an option. Thus, the only way to shield your goal when standing next to the sweets at the supermarket checkout is to invest enough willpower to sustain the temptation of the sweets nevertheless. This example shows how cognitive control adjusts behavior in such a way that the probability of goal attainment is increased. Simply put, without cognitive control, you would be a complete slave to your momentary desires. In fact, this is what can be observed when standing next to a row of sweets with a toddler that lacks a fully developed cognitive control system.

This everyday example shows that the functions subsumed under the term ‘cognitive control’ correspond closely to what is named ‘volition’ in motivational psychology. The term ‘volition’, in turn, is originally based on the term ‘will’ (Ach, 1910;

cf. Goschke, 2002) and, not surprisingly, the importance of this construct prompted researchers already more than 100 years ago to contemplate and examine its nature, purpose and underlying mechanism (Ach, 1910; James, 1890). However, though arousing the interest of researchers early on, the notion of a ‘will’ and, by that, the examination of cognitive control processes, was ignored or even deemed as unscientific for some considerable amount of time[1]. It was only with the so-called ‘cognitive revolution’ in the 1970ies that questions concerning the control of cognitive functions regained attention. A hallmark definition coined during that time is the qualitative differentiation between so-called ‘automatic’ versus ‘controlled’ processes (e.g., Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Processes that are considered as ‘automatic’ are triggered ‘bottom-up’ by environmental stimuli and happen fast and effortless, using up relatively little processing resources. In contrast, processes that are considered as ‘controlled’ exert their influence ‘top-down’ (e.g., they rest on intentions), happen rather slow and exhaust a fair amount of processing resources[2].

An everyday example that perfectly illustrates the distinction between automatic and controlled processes is driving a car. If you are new to driving, say, for example, at the age of 18, you are most likely driving in a controlled processing mode. You have to intentionally recall every step - how do I turn on the engine? How do I turn on the lights? How do I brake? How do I not stall the engine? This is, if you recall or imagine it, very exhausting and costs a fair amount of time. If you are, on the other hand, an experienced driver, say, at the age of 28, you are most likely driving in an automatic fashion. That is, you don’t have to intentionally recall how to operate the driving system but ‘just do it’. This is, obviously, much less exhausting and time-consuming. As can be inferred from that example, processes get more automatic the more they are practiced (Shiffrin & Schneider, 1977). Another major difference between automatic and controlled processes is the higher susceptibility of controlled processes to interference (cf. Goschke, 2003; Botvinick & Cohen, 2014). Imagine, for example, you are driving a car with the radio

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[1] According to Goschke (2002), the reason for this grounds in the wrong idea that the term ‘will’ as used in volitional psychology implicates a liberal view of the term ‘will’ as used in philosophy.

[2] The qualitative distinction of cognitive processes in automatic versus controlled was fundamental for today’s research on the topic of cognitive control. However, it turned out to be too absolute in the years following (e.g., Kahneman & Treisman, 1984; Cohen et al., 1990; cf. Goschke, 2002; 2003). Instead of viewing cognitive processes as being unequivocally automatic or controlled, the contemporary view is that they are placed on a continuum. That is, a process is assumed to be more or less automatic, depending on how often it has been acted out in the past (Shiffrin & Schneider, 1977) and depending on which processes currently compete with it (cf. Botvinick & Cohen, 2014; Cohen et al., 1990).

tuned in and your favorite show is broadcasted at that moment. At the age of 28, when driving in a highly automatized fashion, listening to the radio show probably wouldn’t interfere with your driving much. At the age of 18, however, when having to drive in a controlled manner, listening to that radio show most certainly would interfere with your driving performance.

A classic experimental paradigm that is often used to investigate automatic versus controlled processes is the so-called Stroop task (Stroop, 1935; for a review, see MacLeod, 1991; cf. also Posner & Snyder, 1975). In a standard version of this task, several color words are presented in varying print colors. Subjects’ task is to either read the color word aloud or name the color the word is printed in. Reading the word depicts an instance of automatic information processing, as reading is a highly-trained process, at least in literate persons. Naming the color, in contrast, has to be done in a controlled mode, as color-naming of words is not something we do on a regular basis. This difference in processing modes shows in task performance: as elaborated above, controlled processes are more demanding and thus color naming results in increased reaction times (RTs) and error rates (ERs) as compared to word reading. Furthermore, similar to the observation that listening to a radio show while driving a car affects your performance more severely when you have to drive in a controlled way as opposed to an automatic way, interference in the Stroop task (when color word and print color mismatch, such as the color word RED printed in green) results in much higher performance costs in the color naming task as opposed to the word reading task. That is, when having to indicate the color of ‘incongruent’ stimuli (interference stimuli, such as RED printed in green) as compared to ‘congruent’ stimuli (non-interference stimuli, such as RED printed in red), RTs and error rates increase. This interference-induced performance deficit in the color naming task is termed the ‘Stroop effect’ (cf. MacLeod, 1991). The Stroop effect is a highly consistent finding in experimental psychology and is of major importance to the present thesis, which is why the Stroop task is used as an illustrative model in the following.

THE EXECUTION OF COGNITIVE CONTROL

A further important step in cognitive control research was made by Cohen, Dunbar, and McClelland (1990) by describing a PDP (parallel-distributed processing; Rumelhart, Hinton, & McClelland, 1986) model of the Stroop task. The authors' aim was to simulate empirical findings of the Stroop task performance in order to learn more about them (cf. Figure 1; cf. Botvinick & Cohen, 2014). Thus, while the categorization of processes as being automatic or controlled was rather phenomenological by nature, this model was used explicitly to elucidate the *mechanism* behind cognitive control effects. PDP models build on the theory of connectionist neuronal networks. They consist of several layers of processing units that represent simplified models of neurons (or neuronal networks, respectively). Those units activate each other by means of weighted connections (representing synaptic junctions). They transform (internal or external) environmental signals from layers of 'input' units over layers of 'associative' units to layers of 'output' units, mimicking cognitive processes represented in the central nervous system. More specifically, in the PDP model by Cohen and colleagues, performance in the Stroop task was simulated as energy that flows from input units representing specific stimulus features (color and word dimension) over (unspecified) associate units to output units representing specific reactions (e.g., 'say "Blue"' or 'say "Red"').

The relative automaticity of the word reading task as compared to the color naming task is represented in the model as a stronger pathway between word input units and response units as compared to the pathway connecting color input units with response units. To illustrate how the PDP model simulates the performance benefit of an automatic over a controlled process, imagine presenting the color word RED printed in blue, leading to the activation of the pathways highlighted in green in Figure 1. As the 'word reading' pathway is more developed (i.e., the more automatic process; in the figure, this is represented by bold lines) as compared to the 'color naming' pathway, the model reaches the output unit ' "Red"' faster than it reaches the output unit '"Blue"'. Indeed, as reading a word is the much more habitual response when confronted with a colored word as compared to naming its color, (literate) subjects would, when confronted with such a stimulus, most certainly read the word instead of naming its color.

Now, here shows the revolutionary character of the Stroop model by Cohen and colleagues. By introducing a ‚task unit‘, their model for the first time was able to simulate effects of cognitive control in a classic experimental paradigm. More specifically, the model simulates the ability of participants to name the color of a colored word stimulus, although the automatic response would be to read it out loud. In the task layer, both color naming (i.e., the instruction to name the color) and word reading (i.e., the instruction to read the word out loud) are represented as units. If the given task is to name the color of a Stroop stimulus, the model activates the color naming unit. The color naming unit, then, exerts influence on the associative layer which results in the increased weighting of the color naming pathway[3]. The result is that, in this example, the model generates the answer 'Blue'. Thus, Cohen and colleagues showed for the first time that the execution of cognitive control can be simulated by the implementation of processing units that *actively maintain and communicate task instructions*.

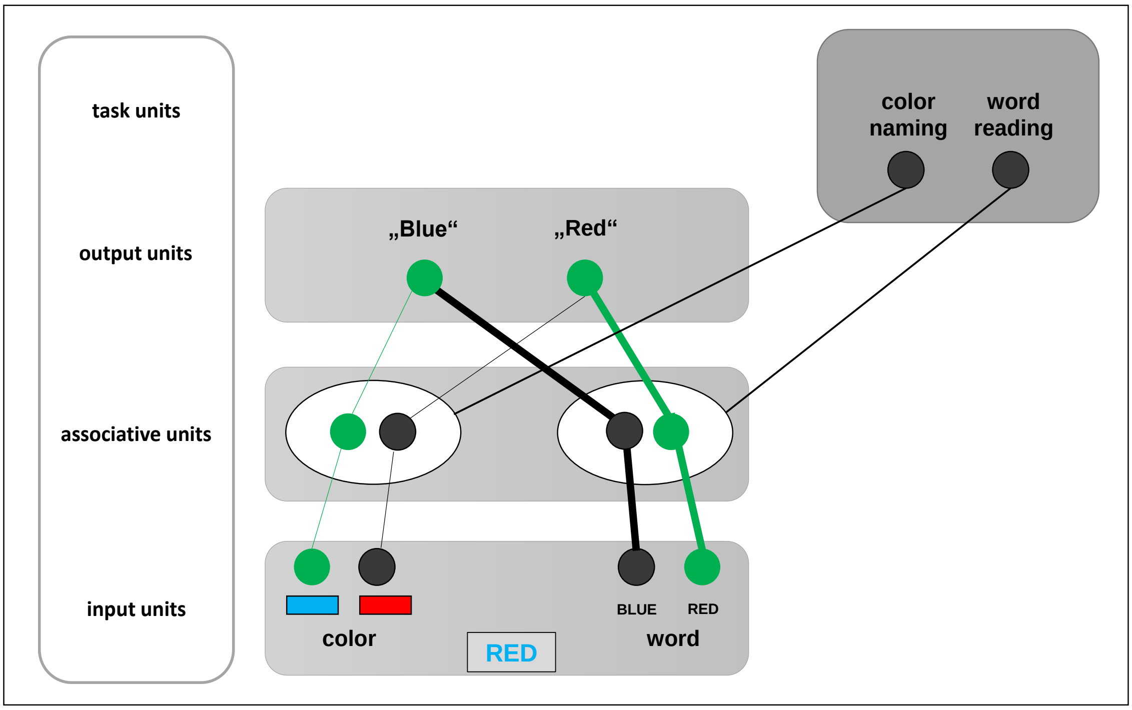

Figure 1. An illustration of a PDP model of the Stroop task (following Cohen et al., 1990; cf. also Botvinick & Cohen, 2014).

The assumption that there exist specific neuronal assemblies (represented as task units in the model by Cohen and colleagues) whose activity supports goal oriented behavior against the influence of interfering information (i.e, in the color naming Stroop

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[3] Cohen and colleagues emphasize that, in their view, both inhibiting as well as facilitating processes contribute to the strengthening of the task relevant pathway.

task, word information) proved very useful in the interpretation of the prefrontal cortex's (PFC) function in the context of cognitive control processes (cf. Botvinick et al., 2014). Indeed, historically, the PFC has been associated with cognitive control functions early on. For example, the Italian neurologist Leonardo Bianchi assumed as early as 1922 that the diffuse behavioral pathologies following partial frontal lobotomy (in dogs) have a common underlying cause: the inability to maintain behaviorally relevant stimulus-response associations (Bianchi, 1922). Likewise, clinical observations made in frontal lobe damaged patients suggest that the PFC is immanently involved in the execution of cognitive control (cf. Cohen, Braver, & O'Reilly, 1996; Duncan, 1986; Milner, 1982). For example, Shallice and Burgess (1991) described frontal lobe damaged patients who, though they scored average on tests of intelligence, perception and language and were able to perform simple tasks (such as, for example, buy a loaf of bread), struggled and failed when they had to coordinate several subgoals in order to reach a superordinate goal (for example, coordinate a sequence of buys to complete a purchase). The authors assumed that the frontal lobe damage resulted in an inability to maintain intentions over a certain delay and thus an inability to perform actions when not triggered directly by a stimulus (i.e., bottom up).

Next to these observations, also structural features of the PFC suggest its prominent role in cognitive control. The PFC is a collection of strongly interwoven neocortical regions that hosts a multitude of connections to other brain regions. The PFC receives input from sensory and motor cortex regions as well as subcortical regions. This manifests the ideal infrastructure to integrate the multimodal information that is needed to act goal-oriented in a complex world. Moreover, the PFC projects back to these regions, allowing it to exert influence on the cognitive processes represented there, i.e., allowing the PFC to exert cognitive control (cf. Miller, 2000). Indeed, in the 1980ies, a series of neurophysiological studies showed first *direct* evidence for the participation of frontal areas in cognitive control processes. More specifically, it has been found that there exist neurons in the PFC that showed stimulus- and reaction-specific activity that lasted until the required reaction was shown. It seems that these neurons maintained a sort of context over time to enable a task-rule-congruent reaction with temporal difference to the triggering stimulus (for a review, see, e.g., Cohen & Servan-Schreiber, 1992; see also Cohen et al., 1996). These and numerous other studies suggest that the PFC is directly involved in the maintenance of mental representations, especially when these have to be shielded from more habitual, automatic behavior. It thus seems reasonable to suggest that the PFC hosts the cell assemblies that are represented as task units in the Stroop model by Cohen and colleagues (1990; cf. Figure 1).

In conclusion, today, it is common knowledge that cognitive control is executed through the active maintenance of goal-relevant neuronal patterns in the PFC (Miller & Cohen, 2001). These patterns of activity represent task or goal representations as well as the representation of the means to achieve these (task) goals. When activated, these neuronal patterns function as tuning signals for cognitive processes that are represented elsewhere in the brain, by that fine-tuning the organism's behavior in such a way that the likelihood of goal achievement is increased (Botvinick & Cohen, 2014). In the following, I will give an overview on the question of how the system knows *when* it should execute cognitive control.

THE SELF-REGULATION OF COGNITIVE CONTROL – THE CONFLICT MONITORING THEORY (CMT)

At the beginning of the twenty-first century, questions in cognitive control research began to alter. While in the late 20th century, questions were mainly mechanistic in nature, now, they shifted towards the examination of the evaluative function of cognitive control: how does the system determine *when* control execution is required? According to Botvinick, Braver, Barch, Carter, & Cohen (2001), most existing theories simply assumed that cognitive control functions emerged whenever they were required, without specifying how this need for intervention should be indicated. In an attempt to overcome this problematic assumption of an 'homunculus' inside the brain that 'just knows' when cognitive control adjustments are required, Matthew Botvinick, Cameron Carter and their colleagues framed their influential conflict monitoring theory (CMT) (Botvinick et al., 2001; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter et al., 1998), reaching out to finally "disarm[ing] the homunculus" (Botvinick et al., 2014; p. 8). The authors built on an idea already articulated by British-Canadian psychologist and philosopher Daniel E. Berlyne at the end of the 1950ies (Berlyne, 1957; 1960), proposing that conflicts in information processing (such as the conflict between saying 'Blue' or 'Red' as presented in Figure 1 above) lead to compensatory adjustments in subsequent information selection. Basically, this means that conflicts translate as the need for more control in a given moment and that by detecting such conflicts, cognitive control self-regulates its involvement according to current necessity.

More specifically, Botvinick and colleagues suggested that conflicts are detected by the anterior cingulate cortex (ACC), a region in the medial surface of the frontal lobe. This detection is signaled to the dorsolateral prefrontal cortex (dlPFC), which consequently executes cognitive control by biasing subsequent information processing in a goal-directed manner. Implementing the CMT in the PDP Stroop model presented above, the conflict monitoring unit (CMU; representing the ACC) would thus, when conflict is detected at the response level (or at other processing stages[4]) in trial N signal the need for a control increase to the task unit layer (representing the (dl)PFC). Here, in turn, the task unit to ‘name the color’ would be activated[5], resulting in an increased weighting of the color naming pathway (cf. Figure 2). In this way, the probability for a conflict-induced performance decrease in N+1 would be reduced by a conflict in the current trial N, as here, conflict detection leads to increased processing of the task-*relevant* color dimension but decreased processing of the task-*irrelevant* word dimension.

Indeed, Botvinick and colleagues (2001) were able to offer compelling evidence for the CMT in two simulation studies. In the first study, Botvinick and colleagues sorted diverse ACC-activating task conditions into three superordinate categories (‘tasks that require response override’, ‘tasks that require ‘underdetermined’ reactions’, and ‘errors’). The authors argue that conflict can be conceptualized as *crosstalk (concurrent activation) between different processing pathways*, so that in response override tasks, conflict is experienced because a predominant, but wrong reaction competes with a weaker, but correct reaction. In underdetermined response tasks, conflict occurs because of the presentation of a stimulus that activates several equally correct reactions (e.g., in a verb generation task). And finally, ACC activation in error commission is explained as caused by conflict between the incorrect but already executed response and the correct response that comes to mind only shortly after error commission[6].

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[4] Botvinick and colleagues (2001) emphasize that conflicts can occur at any information processing stage, for example at the stage of stimulus evaluation, memory representation or response selection (see also Carter & van Veen, 2007).

[5] The question of how the cognitive system knows *which* task unit has to be chosen, or, more generally, how the cognitive system decides where control should be deployed to, has come into the focus of cognitive control research only recently and is a highly interesting topic in itself but goes beyond the scope of the present thesis (for a comprehensible review, see e.g. Botvinick & Cohen, 2014).

[6] Other authors that consider errors as an extreme form of unresolved conflict include Yeung, Botvinick, and Cohen (2004) and Shenhav, Botvinick, and Cohen (2013).

Now, Botvinick and colleagues re-used and extended well-established computer simulations of paradigms including these task conditions by adding a simple CMU (representing the ACC). The CMU estimated the activation (i.e., the amount of conflict) over the response layer for different task conditions in a given model; this activation was then compared with the respective level of ACC activation as found empirically. For example, in a Stroop task model (Cohen & Huston, 1994), CMU and ACC activation were compared for congruent and incongruent trials. Indeed, the increased ACC activation in incongruent as compared to congruent trials as found empirically was successfully mimicked by the CMU activation pattern. The same was true for a word stem completion model (McClelland & Rumelhart, 1981) and an Eriksen flanker model (Servan-Schreiber, 1990; cf. Botvinick et al., 2001): in each simulation, the conceptualization of the ACC as a CMU confirmed neuroimaging findings of increased ACC activation in conditions of increased conflict levels.

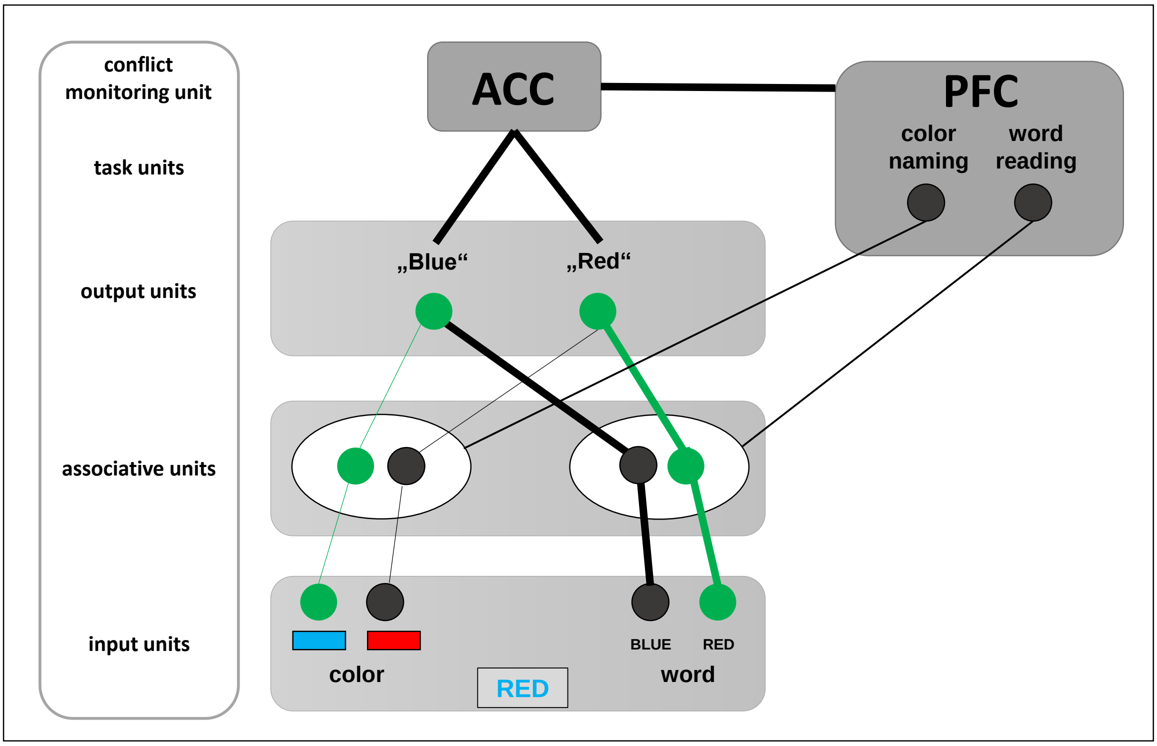

Figure 2. An illustration of a PDP model of the Stroop task that is extended by a conflict monitoring unit (CMU) representing the ACC (following Cohen et al., 1990; Botvinick & Cohen, 2014; Botvinick et al., 2001).

In the second empirical part of their article, Botvinick and colleagues (2001) report a simulation generated to test their major hypothesis: the idea that the ACC is critically involved in the self-regulation of cognitive control. This assumption was originally motivated by behavioral studies reporting online adjustments of cognitive control (as measured in their corresponding performance levels). For example, Botvinick and colleagues review a study by Gratton and colleagues (Gratton, Coles, & Donchin, 1992) that reports decreased interference effects in post-conflict trials in an Eriksen flanker task (also called the 'Gratton effect'). In an Eriksen flanker task, participants have to respond to a centrally presented target stimulus that is surrounded by irrelevant flanker stimuli that either are assigned to the same response as the target stimulus (a congruent (C) trial, benefitting performance) or not (an incongruent (I), a 'conflict' trial, deteriorating performance). The Gratton effect describes the observation of a smaller congruency effect following incongruent trials. More specifically, performance in incongruent trials following incongruent trials (II trials) is increased as compared to performance in incongruent trials following congruent trials (CI trials), while performance in congruent trials following incongruent trials (IC trials) is decreased as compared to performance in congruent trials following congruent trials (CC trials). This data pattern has been replicated often for different response tasks (e.g., Botvinick et al., 1999; Egner & Hirsch, 2005; Kerns et al., 2004; Kunde, 2003; Stürmer & Leuthold, 2003; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Ullsperger, Bylsma, & Botvinick, 2005; Wühr & Ansorge, 2005). In the case of the Stroop task, the Gratton effect is explained by a post-conflict reduction of the influence of the irrelevant word pathway, while the post-conflict influence of the relevant color pathway is enhanced (Egner & Hirsch, 2005; see Carter & van Veen, 2007)[7].

Now, Botvinick and colleagues opted to simulate this data pattern (as well as other observations that can be interpreted as online adjustments of cognitive control according to conflict levels, i.e., the trial-type frequency effect in the Stroop task and changes in performance following errors) by letting the level of cognitive control vary from trial to trial. More specifically, the computational models in this second simulation study were generated in such a way that the influence of the relevant task unit should be increased if

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[7] It should be noted, however, that there is an ongoing debate in cognitive psychology whether sequential adaptation is an instance of cognitive control execution, as presented here, or an effect of "lower" cognitive processes such as episodic memory (i.e., retrieval or priming effects; see e.g. Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). However, most research up to date has shown sequential modulation even when controlling for episodic memory effects. This suggests that conflict adaptation is produced by a combination of episodic and cognitive control processes. For a recent discussion of theoretical and practical guidelines in the investigations of sequential modulation effects see Duthoo et al. (2014) and Egner (2014).

the CMU detected conflict in a previous trial, or reduced if the CMU did not detect conflict in a previous trial[8]. Again, the simulations were able to replicate the behavioral findings elaborated above.

In conclusion, Botvinick and colleagues (2001) offered compelling evidence for the validity of the CMT in two simulation studies. Nevertheless, the idea that the ACC functions as a CMU in the service of cognitive control regulation has not been accepted in all labs. In the following section, I will briefly discuss alternative interpretations of the function of the ACC and how these controversies have been integrated in an extended version of the CMT by Matthew Botvinick in 2007. It is this theory that gave the starting point for the studies presented in this thesis.

CHALLENGING THE CMT

As elaborated above, in the framework of the CMT, the ACC is conceptualized as a region whose major function is to detect and signal conflicts in the ongoing processing stream. However, while at the end of the 20th century it was widely believed that the ACC was involved in cognitive control *somehow* (D'Esposito et al., 1995; LaBerge, 1990; see also Botvinick et al., 2001), there was by no means a consensus on its *exact* role. Indeed, the ACC had been found to be activated in a wide variety of tasks, such as tasks involving perceptual target detection, motor control, language, learning, memory, imagery, dual task performance, and so forth (cf. Botvinick et al., 2001; Botvinick, 2007). Obviously, these tasks vary considerably, so that it was difficult to pin-point the underlying cognitive function that could explain the ACC activity in all of them.

Originally, the CMT grew out of the error detection theory (EDT) of ACC functioning (e.g., Falkenstein et al., 1991; Falkenstein et al., 2000; cf. Carter & van Veen, 2007). The EDT proposed that the ERN (error related negativity), a negative waveform that peaks 50-100 ms after executing an erroneous response or 100-150 ms after electromyograph onset, is generated in the ACC and represents the detection of a mismatch when comparing the representation of the actual (erroneous) response with the representation of the intended (correct) response. As can be seen from this rationale, the

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[8] More precisely, in the simulations by Botvinick and colleagues (2001), control in a given trial N was computed by integrating the conflict signals generated over several preceding trials. Though this probably represents cognitive control effects in a more naturalistic way, it is common practice in cognitive control research to investigate effects depending on the conflict level of the immediately preceding trial only.

EDT and the CMT share common grounds in their interpretation of ACC activity as a detection module that signals some kind of mismatch (i.e., conflict) between different representations. However, the CMT was soon recognized to be more general and thus more parsimonious; one major advantage of the CMT is that, in contrast to the EDT, it can explain ACC activity in *correct* high conflict trials, where intended and actual response always match, obviously (Carter & van Veen, 2007).

Another early 21st century account of ACC functioning was the so-called selection-for-action theory (SFA). Here, the ACC is associated with an executive role in cognitive control. More specifically, Allport (1974) defined the expression *selection for action* as a mechanism that “can selectively designate a specified subset of the available, and potentially relevant, sensory information to have control of a given effector system, and can selectively decouple the remainder from such control” (p. 397). That is, in the framework of the SFA, the ACC is believed to select and couple specific responses with available sensory input (see Holroyd & Coles, 2002). In a further elaborated version of the SFA, Paus et al. (1993) suggested that the ACC receives executive orders from the dlPFC and sends them further along to motor effectors. The selection of the *appropriate* effector is supported by the mesencephalic system. This connects the SFA with a prominent theory of ERN functioning by Holroyd and Coles (2002). In their view, the ERN reflects an inhibition of mesencephalic dopamine influx into the ACC. Dopaminergic neurons that project into the ACC are inhibited, according to that theory, when a certain outcome is evaluated as being less positive than expected. By that, the ACC is trained over time to choose the motor controllers (that can be almost every structure in the brain, from the amygdala to the dlPFC) that lead to the most effective outcome in a given situation. Thus, also in the ERN theory by Holroyd and Coles (2002), the ACC is given an executive function.

The major difference between the CMT on the one hand and the SFA (including the framework as put forward by Holroyd and Coles (2002)) on the other hand is that the CMT ascribes the ACC a monitoring function, while the latter ascribes the ACC an action selection function. However, there have been elegant studies that shed light on this controversy. Botvinick and colleagues (1999) directly tested predictions of the SFA against predictions of the CMT in a fMRI study using an Eriksen Flanker paradigm. They made use of the fact that selection-for-action and response conflict are inversely correlated in trials following congruent versus trials following incongruent trials, an effect that is especially obvious for currently incongruent trials. In iI trials, distracting influence of incongruent flankers is minimal, that is, in these trials, SFA (i.e., the engagement of mechanisms that couple the target stimulus with a specific response) should be high while response conflict should be low. In cI trials, in contrast, distracting influence of incongruent flankers is high, that is, in these trials, SFA should be low while response conflict should be high. Analysis of the imaging data revealed that ACC activity was higher for cI than for iI trials, suggesting that the ACC is responsible for the monitoring of response conflicts rather than the execution of cognitive control.

A second imaging study yielding results in support of the CMT was conducted by Carter and colleagues (2000). In that study, participants engaged in a verbal version of the Stroop task and ran through blocks with high and low frequencies of conflict trials. Similar to the study by Botvinick and colleagues (1999), Carter et al. presumed that the activity level of the ACC in high versus low conflict blocks should be predictive of the ACC's role in cognitive control processes. Carter et al. assumed that blocks with high conflict frequencies would generate high expectancies for conflict stimuli in participants, while blocks with low conflict frequencies would generate low expectancies for conflict stimuli. Now, if participants have high conflict expectancy (in blocks with high conflict frequency), they should increase executive action selection processes (SFA) in order to be prepared for conflict experience. By that, actual conflict experience would be diminished in these blocks. On the other hand, if participants have low conflict expectancy (in blocks with low conflict frequency), they should diminish engagement in action selection processes (SFA) because preparation would not be too necessary but would experience high conflict levels when confronted with a conflict stimulus. Thus, high ACC activity in frequent-conflict blocks should support the SFA, while high ACC activity in infrequent-conflict blocks would support the CMT. Again, the results of this second fMRI study speak for the CMT.

While the evidence favouring the CMT over the SFA accrued over time[9], another major challenge for the CMT arose from a study that was conducted in 2002 by Gehring and Willoughby (see also Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004). In this EEG study, participants had to engage in a gambling task, that is, they had to choose

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[9] As a sidenote, another observation that supports a monitoring as opposed to an executive function of the ACC is the fact that ACC activity is high on erroneous trials where selection-for-action should be virtually absent (cf. Botvinick et al., 2001).

between two rectangles which were associated with different monetary gains or losses. After choosing, participants received feedback that informed them on the amount of money they had won or lost. Moreover, this performance feedback showed participants if they had won or lost more or less money if they had chosen *the alternative option*. In that way, the authors were able to disentangle influence of actual error feedback from influence of loss feedback; most of the times, these conditions are confounded in standard laboratory tasks. What they found is that the medio-frontal negativity (MFN), a negative deflection often interpreted as representing the same neuronal activity inside the ACC that is otherwise known as the ERN, was more strongly correlated with the loss feedback than the error feedback per se. Thus, Gehring and Willoughby (2002) suggested that what the ACC actually monitors for is not the instance of an error but the *motivational impact* an error entails. More general, this and other studies (Bush et al., 2002; Holroyd & Coles, 2002; Nieuwenhuis et al., 2004) can be subsumed as favouring an outcome evaluation account (OEA) of ACC functioning, proposing that the ACC reacts particularly strong to instances of aversive action outcomes. This view is further supported by studies showing ACC engagement in conditions of negative feedback (Miltner, Braun, & Coles, 1997), monetary loss (Blair et al., 2006; Kahnt et al., 2009; Liu et al., 2011), self-experienced pain (Rainville, 2002), the mere observation of pain in others (Singer et al., 2004; Lamm, Decety, & Singer, 2011) and social rejection (Eisenberger, Lieberman, & Williams, 2003; Kawamoto et al., 2012).

While these results cannot be explained by the original conceptualization of the CMT, Botvinick et al. addressed some of these contradictions already in 2001[10]. They acknowledged that conflict monitoring might only be one of several functions the ACC holds, but also proposed the possibility to interpret these aversive outcomes as sharing its purpose with the purpose of conflict detection: to inform the system of the need to reallocate control resources, that something is off track[11]. In 2007, Botvinick built on that original thought and suggested an integrative view of the OEA and CMT. He reviewed

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[10] Majorly, Botvinick et al. (2001) referred to the finding of enhanced ACC activity in the Miltner et al. (1997) study, but also mention work by Hsieh et al. (1994) and Jones et al. (1991) that showed ACC activation in response to pain and itch. Here, Botvinick and colleagues cleverly argue that pain- and itch-induced ACC activity might as well represent conflict between the automatic urge to ease the pain such as by scratching and the instructed behaviour of sitting still / engage in the task while participating in the experiment.

[11] Botvinick et al. (2001) mention that there still exists an important conceptual difference between conflicts in information processing and aversive outcomes in general. While aversive outcomes such as pain, negative feedback and social exclusion inform the system that something *has gone* wrong, conflicts inform the system that something *might go* wrong.

existing literature of both sides and concluded that first, the ACC seems to get engaged whenever an outcome is aversive, and that second, the detection of such aversive events seems to drive a form of avoidance learning, which is however executed in other parts of the brain. This interpretation of data fits with more detailed versions of the OEA as put forward in some work (see e.g., Bush et al., 2002; Gehring & Willoughby, 2002; Holroyd & Coles, 2002), stating that the overall function of the ACC's sensitivity to aversive outcomes is to guide decision making so as to optimize performance outcomes. Most importantly, it also fits with the CMT, as it conceptualizes the conflict experience as a form of negative reinforcer that punishes sloppy cognitive control.

To conclude, in 2007, Botvinick integrated two influential theories of ACC functioning into one comprehensible account. According to that, the ACC registers any form of aversive event in an organism's environment, signalling the need to adapt behavioural strategies in a way that minimizes future costs. Thus, what Botvinick's work implies is that conflicts in information processing are experienced as aversive, too. This is an assumption that, although crucial for the validation of the extended version of the CMT, had not been tested until 2012, as will be further elaborated in the following.

CONFLICTS AS AVERSIVE SIGNALS

Although the suggestion that conflicts are inherently aversive is of major importance to the validity of the extended version of the CMT as presented by Matthew Botvinick (2007), it has long been untested. In 2012, however, Dreisbach and Fischer for the first time directly demonstrated conflict aversiveness (Dreisbach & Fischer, 2012a). To that aim, the authors modified an acknowledged version of the original affective priming paradigm by Fazio, Sanbonmatsu, Powell, and Kardes (1986; see also Fazio, 2001). In standard versions of the affective priming tasks, participants have to react to target stimuli (usually words or pictures) after being primed by positive or negative primes (usually words or pictures). The typical finding is that performance is increased if prime and target share the same valence. The most common explanation is that priming with an affective stimulus pre-activates an affect-congruent network, thus lowering the threshold for reactions to same-valence target stimuli. Now, in two experiments, Dreisbach and Fischer used Stroop conflict and non-conflict stimuli as primes and positive and negative words and pictures as targets. The idea was that if Stroop conflicts are aversive, then they should yield the same data pattern that is found when priming participants with other aversive primes. Indeed, this is what was found: being primed with Stroop conflicts, participants reacted faster and less error-prone to negative target stimuli as compared to positive target stimuli. This study was the starting point for the present thesis - I will now give a short overview on the aims and hypotheses of the three peer-reviewed articles that are presented in the next part of this thesis.

STUDY 1 aimed at de-confounding the results of Dreisbach and Fischer (2012a) from a possible effect of processing fluency. Dreisbach and Fischer made use of target stimuli with affective valence. That is, being primed by conflict or non-conflict Stroop stimuli, participants had to categorize positive or negative target stimuli according to valence. This, however, may have induced a confound that renders the interpretation of results difficult. Using affective target stimuli rendered the possibility that observed 'affective priming effects' are actually caused by an overlap of processing fluency characteristics between conflict prime and negative target and non-conflict prime and positive target stimulus, on the other hand. Thus, the effect as reported by Dreisbach and Fischer may not reflect an instance of conflict priming, but may instead reflect an effect of primed processing fluency. Thus, the aim of this thesis' first study was to de-confound the conflict priming effect from aspects of processing fluency and thus to offer more unequivocal evidence for the aversiveness of conflicts in information processing. To this end, two experiments were conducted that included neutral target stimuli (Experiment 1A: neutral German words; Experiment 1B: Chinese pictographs). The reproduction of the conflict priming effect with these new dependent variables was expected.

STUDY 2 of this thesis was designed to examine the time course of Stroop conflicts' aversiveness. While typically, affective priming effects can only be found with short prime presentation times, the time course of the affective valence induced by conflicts in information processing may substantially differ from that. To this end, three experiments were conducted to examine the time characteristics of the conflict priming effect in more detail (Experiments 2A, 2B and 2C). Prime presentation duration as well as stimulus onset asynchronity (SOA) was varied systematically. It was expected that the affective valence produced by conflict primes is similar in nature to other affective stimuli, such that the conflict priming effect would be most obvious with short prime presentation times.

STUDY 3, finally, aimed at exploring the function of conflict aversiveness: is conflict aversiveness a necessary precondition for conflict adaptation to occur? To this aim, two experiments were conducted in which the aversiveness of conflict stimuli was manipulated by adding additional aversiveness (in the form of perceptual disfluency) on some trials (Experiments 3A and 3B). We reasoned that if it is aversiveness that triggers conflict adaptation, then increasing the aversiveness of a conflict stimulus should result in increased conflict adaption effects.

PART II

PEER-REVIEWED STUDIES

STUDY 1

Conflicts as Aversive Signals: Conflict Priming Increases Negative Judgments for Neutral Stimuli

Julia Fritz, Gesine Dreisbach

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ABSTRACT

Botvinick (2007) recently suggested that competing theories of the monitoring function of anterior cingulate cortex (ACC) for cognitive control might converge on the detection of aversive signals in general, implying that response conflicts, a known trigger of ACC activation, are aversive, too. Recent evidence showing conflict priming (i.e., faster responses to negative targets after conflict primes) directly supports this notion but remains inconclusive with regard to possible confounds with processing fluency. To this end, two experiments were conducted to offer more compelling evidence for the negative valence of conflicts. Participants were primed by (conflict and non-conflict) Stroop stimuli and subsequently had to judge the valence of neutral German words (Experiment 1A) or Chinese pictographs (Experiment 1B). Results show that conflict, as compared with non-conflict, primes led to more negative judgments of subsequently presented neutral target stimuli. The findings will be discussed in the light of existing theories of action control highlighting the role of aversive signals for sequential processing adjustments.

INTRODUCTION

Cognitive control describes the human ability to flexibly adapt goals and actions in accordance with internal and external needs (Miller & Cohen, 2001). One of the main mechanisms underlying such cognitive flexibility is a monitoring function that supervises the ongoing processing stream for significant information, like for example error feedback or co-activation of conflicting response tendencies. Once, an error or conflict signal is detected, cognitive control is increased in order to solve the conflict or increase accuracy, respectively (e.g. Botvinick, Braver, Barch, Carter, & Cohen, 2001; Holroyd & Cole, 2002; Yeung, Botvinick, & Cohen, 2004). From brain imaging studies, there exists broad empirical evidence that the anterior cingulate cortex (ACC) plays a major role in this monitoring process. For example, Botvinick and colleagues (2001), in their influential conflict monitoring theory, suggest that the ACC is activated by response conflicts and then signals the need for additional control to the dorsolateral prefrontal cortex (MacDonald, Cohen, Stenger, & Carter, 2000; Kerns, Cohen, MacDonald, Cho, Stenger, & Carter, 2004). Behaviorally, this sequential control adaptation is reflected in a reduced response conflict in trial N after a response conflict in trial N-1 (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Gratton, Coles & Donchin, 1992; Notebaert, Soetens, & Melis, 2001; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr & Ansorge, 2005; for a review see Egner, 2007). However, this ACC model of conflict adaptation was recently challenged by several studies showing that the ACC is not only activated by response conflicts but also by social rejection/exclusion (Eisenberger, Lieberman, & Williams, 2003), monetary losses (Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004), and experienced and witnessed pain (Rainville, 2002; Singer et al., 2004; for a review see Shackman, Salomons, Slagter, Fox, Winter, & Davidson, 2011). Therefore, Botvinick (2007) presented an integrative account of ACC function, suggesting that ACC might monitor and detect just any aversive signal in the ongoing processing stream. The significance of this assumption should not be underestimated as it would make the ACC monitoring theory applicable to a much wider range of tasks and situations. However, since most of the evidence in favor of the monitoring theory of ACC function stems from response conflict paradigms, it is essential to show that response conflicts themselves actually serve as an aversive signal.

The notion of conflict as an aversive signal so far has mostly been supported by indirect evidence. Using an Eriksen Flanker paradigm, van Steenbergen, Band and Hommel (2009) provided first indirect evidence for the aversive nature of conflicts. They showed that reward stimuli randomly (and unconditional of the actual performance) following conflict trials eliminated conflict adaptation effects. This was taken as evidence that the positive affect induced by the reward signal counteracted the negative valence of the conflict, thereby eliminating the signal for control adjustments (but see Braem, Verguts, Roggeman, & Notebaert (2012), who found enhanced conflict adaptation following action contingent reward). Furthermore, Dreisbach and Fischer (2011) provided support that the negative valence of conflicts and not the response conflict itself, triggers sequential processing adjustments. In a magnitude comparison task with no response conflict involved, participants had to decide whether a presented number word was smaller or larger than five. The number words were either written in an easy-to-read (*fluent*), or a hard-to-read (*non-fluent*) font. It is well-documented that stimuli that are processed fluently induce positive affect, whereas stimuli that are processed non-fluently induce negative affect (e.g., Reber, Schwarz, & Winkielman, 2004; Winkielman & Cacioppo, 2001). Importantly, the results presented by Dreisbach and Fischer (2011) show that non-fluent and thus aversive number words induced sequential processing adjustments resembling conflict adaptation effects: the fluency effect (faster responses for fluent than for non-fluent trials) was smaller following non-fluent trials than following fluent trials. This was taken as evidence, that even in the absence of conflict, cognitive effort increased after non-fluent stimuli. Combining literature that highlights aversiveness of non-fluent stimuli with the observation that they induce conflict-like sequential adaptation effects, it can thus be reasoned that it is the aversiveness inherited in both types of stimuli that triggers the control adjustments. Further evidence for the aversiveness of conflict comes from Schouppe, De Houwer, Ridderinkhof and Notebaert (2012) who recently showed that Stroop conflict stimuli promote avoidance behavior. The probably most direct approach to study the affective valence of conflicts was taken by Dreisbach and Fischer (2012a), who administered a conflict priming task, inspired by the affective priming paradigm first introduced by Fazio, Sanbonmatsu, Powell, and Kardes (1986). In a typical affective priming paradigm, participants encounter a prime stimulus of certain valence (e.g., a positive or negative picture), followed by a target stimulus of certain valence (e.g., a positive or negative word), with the instruction to evaluate the valence of the target stimulus as fast and accurately as possible. The typical finding is that positive primes facilitate responses to positive targets, whereas negative primes facilitate responses to negative targets. Now, Dreisbach and Fischer (2012a) used congruent and incongruent Stroop color words as (presumably) affective primes, and positive and negative words/pictures as targets. As predicted, they found faster reaction times (RTs) for negative targets following incongruent Stroop primes and slower RTs following congruent Stroop primes. This was taken as first direct evidence for the negative valence of conflicts. However, and alternatively, the results might also be interpreted in terms of a match of processing fluency between prime and target, as will be further outlined below. Therefore, the aim of the study presented here was to provide more unequivocal evidence for the aversive nature of conflicts.

Affective priming effects are commonly referred to as effects of valence compatibility (Fazio et al., 1986; Fazio, 2001): Responses are slow whenever the valence of prime and target are incompatible, and fast whenever both valences are compatible. However, it is conceivable that conflict primes and negative targets in the study by Dreisbach and Fischer (2012a) matched in more than just the valence dimension. The numerous variants of priming paradigms suggest that the possibilities for an overlap in dimensions and thus compatibility effects between prime and target stimuli are abundant (see Kornblum, Hasbroucq, & Osman, 1990). For instance, prime and target can overlap semantically, such as *dog* priming *cat* instead of *sun*, or orthographically, such as *house* priming *mouse* instead of *rose* (for a review, see Gulan & Valerjev, 2010). Importantly, findings by Chang and Mitchell (2009) suggest that results in compatibility-dependent tasks with more than one dimensional overlap between prime and target can be confounded with unnoticed prime-target relations. More specifically, the authors report that findings in the implicit association task (IAT; Greenwald, McGhee, & Schwartz, 1998), an associative task closely related to affective priming paradigms, can be confounded with artifacts due to underlying compatibility in terms of *processing fluency*. Perhaps, then, faster responses in non-conflict prime/positive target and conflict prime/negative target combinations (Dreisbach & Fischer, 2012a) were not the result of valence associations, but were caused by matching processing characteristics: in particular, positive targets and non-conflict primes might be processed more easily, and negative targets and conflict primes might be processed less easily (see Unkelbach, Fiedler, Bayer, Stegmüller, & Danner, 2008; Scott, O'Donnell, Leuthold, & Sereno, 2009). One theoretical account, the so-called ‘density hypothesis’, proposes that the speed advantage in the processing of positive information as compared to negative information is caused by the higher density of positive information in memory (i.e., positive concepts such as “happy” and “content” are more similar than negative concepts such as “angry” and “sad”, for example; Unkelbach et al., 2008). Because of this alleged density, processing of a positive stimulus (in comparison to processing of a negative stimulus) immediately triggers an entire network of equally valenced information. This fast and wide-spread activation manifests in higher processing fluency for positive information, whereas the processing of negative information triggers a rather uncompressed network, manifesting in lower processing fluency for negative information. Applied to the conflict paradigm used previously, this means that priming effects between non-fluently processed negative targets and non-fluently processed incongruent Stroop stimuli (as compared to congruent Stroop stimuli) might rest on similar processing characteristics instead of valence congruency. That is, even though affect and processing fluency may represent two sides of the same coin (Reber et al., 2004; Winkielman & Cacioppo, 2001), it cannot be ruled out that the priming effects observed by Dreisbach and Fischer (2012a) were mainly mediated by an overlap in processing fluency between conflict prime and target. To this end, in the experiments presented here we again administered a conflict priming task but this time only used neutral targets to de-confound possible fluency characteristics from target valence. Participants’ task this time was to spontaneously judge the affective valence of the neutral target stimuli. The rationale is that conflict primes should modulate the affective judgment according to the prime’s valence (e.g. Murphy, Monahan, & Zajonc, 1995; Payne, Cheng, Govorun, & Stewart, 2005). Whereas reaction times (RT) to *categorize* affective target stimuli according to their valence served as dependent measure in the conflict priming paradigm used by Dreisbach and Fischer (2012a), we now measured valence judgments of *affectively neutral* target stimuli (that is, German words in Experiment 1A and neutral Chinese characters in Experiment 1B) following congruent and incongruent Stroop primes. That is, *neutral* target stimuli ensured equivalent processing fluency of targets and thus ruled out the possibility of fluency compatibility confounds. If conflicts are truly aversive in nature, then their negative valence should spread to the otherwise neutral targets when presented shortly after them. We thus expected to find more negative judgments after conflict primes as compared to non-conflict primes.

EXPERIMENTS 1A AND 1B

Method

Participants

In Experiment 1A, 21 right-handed students (13 female, eight male; mean age 25.6 years, *SD* = 5.2), and in Experiment 1B, a separate sample of 24 right-handed students (19 female, five male; mean age 22.2 years, *SD* = 1.8) from the University of Regensburg, participated in exchange of a chocolate bar or 2 Euros. All 45 participants signed informed consent and were debriefed after the session. The data of one participant who showed a strong trend towards positive judgment (more than 75% of target words were evaluated as positive (1A), one participant who was color blind (1B) and one participant who misunderstood instructions (1B), were excluded from analysis, leaving final samples of 20 (1A) and 22 (1B), respectively.

Apparatus and Stimuli

Primes were the German color words for BLUE, GREEN, YELLOW, RED, and PURPLE printed in blue, green, yellow, red, and purple. The print color could either match (non-conflict stimuli) or mismatch (conflict stimuli) the color denoted by the word. Primes and target words were written in Courier New bold, 26pt, each letter subtending a visual angle of approximately 0.7° X 0.7° at a viewing distance of 55 cm. In Experiment 1a, targets were 112 German words (94 nouns, 12 verbs, and 6 adjectives selected on the basis of neutral affective ratings from the Berlin affective word-list reloaded BAWL-R (mean valence ratings: -.001, running on a scale from from 3 (*very negative*) through 0 (*neutral*) to 3 (*very positive*), *SD* = .000; range of ratings: .109; Võ et al., 2009). In Experiment 1b, targets were 144 Chinese pictographs which subtended a visual angle of approximately 8° X 8° and were chosen randomly from an online English - Chinese dictionary[12] (cf. Murphy, Monahan, & Zajonc, 1995; Murphy & Zajonc, 1993; Zajonc, 1968). The pictographs represented nouns, such as ‘wall’, verbs, such as ‘to go’ and adjectives, such as ‘new’. Primes and targets appeared at the center of the screen on a light grey background.

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[12] Online English-Chinese dictionary available at http://www.mdbg.net/chindict/chindict.php

Procedure

Participants had to judge the valence of targets (i.e., German words (1A) or Chinese characters (1B)) that were preceded by Stroop primes. They had to press a right response key to judge the target as positive and a left response key to judge the target as negative ("-" and "y"-key on a QWERTZ keyboard, respectively). This assignment was held constant as people have a natural tendency to associate positive concepts with their dominant body side, i.e. the right hand (Casasanto, 2009). Participants were asked to choose each option at approximately the same rate to minimize potential biases in favor of one response key. To ensure processing of the primes, *catch trials* were interspersed: whenever the prime word was the German word for PURPLE or the primes BLUE, GREEN, YELLOW, or RED were printed in purple, participants had to press the space bar instead of evaluating the following target. As both color and word dimension could denote a potential catch trial, proper encoding of Stroop primes and thus the experience of conflict should be warranted.

Each trial started with the presentation of the Stroop prime for 400 ms, as electrophysiological studies show a peak in conflict-associated negativity at around 400 ms after Stroop stimulus onset (Hanslmayr et al., 2008; Liotti, Woldorff, Perez, & Mayberg, 2000). After the prime, the target appeared and remained on screen until a response was given. Inter-trial-intervals were of 1000 ms length. In erroneous catch-trials, the German word for ERROR appeared on screen.

After a short test to exclude color blindness, the conflict priming task started with two short practice blocks to familiarize participants with the task.[13] Experiment 1A consisted of two experimental blocks of 112 trials, separated by a self-paced break. In a given block, each target word was presented once. More precisely, 48 words were preceded by a congruent prime, 48 by an incongruent prime and 16 by a catch prime in a given block. Prime congruency was thus manipulated trial-wise and random. Moreover, target words that were preceded by a conflict prime in one block were preceded by a non-conflict prime in the second block (order counterbalanced across participants).

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[13] In Experiment 1A, as in the previous study by Dreisbach and Fischer (2012) the experiment started with a short block of 24 Stroop stimuli, where participants had to name the color of the words to make participants familiar with the (aversive character) of the Stroop primes. However, because the error rate for catch trials in Experiment 1A was very low, the short Stroop block was dropped in Experiment 1B, since catch trials successfully ensured the processing of the Stroop primes.

Experiment 1B using 144 different Chinese characters consisted of only one experimental block of 144 trials length, composed of 120 target trials intermixed with 24 catch trials. 60 targets were thus preceded by a congruent prime, 60 targets by an incongruent prime and 24 by a catch prime. Again, the combination of prime congruence and target was random and varied between participants. In both experiments, there was a minimum distance of two and a maximum distance of 8 target trials between catch trials. Experiment 1A lasted about 15 minutes, Experiment 1B about 8 minutes.

Results

Mean error rate in catch trials was low in both experiments (1A: *M* = 4.08%, *SD* = 3.68; 1B: 4.91%, *SD* = 7.41), suggesting participants encoded both word and color dimension properly. For each experiment, proportions of negative/positive judgments as a function of prime (conflict/non-conflict) of the experimental blocks were computed. To test for a general bias in judgment, we conducted two one-sampled t-tests (two-sided) against the null hypothesis of 50%. In both experiments, judgment was unbiased (1A: frequency of positive judgments: *M* = 52.37%, *SD* = 8.56, *t*(19) = 1.239, *p* = .231, *d* = .281; 1B: *M* = 48.58%, *SD* = 8.13, *t*(21) < 1, *p* = .423, *d* = .183).[14]

To test for affective priming effects by conflict primes, we compared mean frequencies of negatively judged targets depending on prime condition. In both experiments, paired t-tests (one-sided) revealed a significant difference between prime conditions (1A: *t*(19) = 2.125, *p* = .024, *d* = 0.475; 1B: *t*(21) = 2.256, *p* = .018, *d* = 0.481). Neutral target stimuli were judged more frequently as negative after conflict than after non-conflict primes (1A: *M* = 48.54%, *SD* = 9.30, vs. *M* = 46.32%, *SD* = 8.95; 1B: *M* = 53.52%, *SD* = 9.35, vs. *M* = 49.31%, *SD* = 9.11, see Figure 3).

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[14] For the sake of completeness, mean reaction times (RT) for each prime-target combination were entered into a 2 (prime congruence: conflict/non-conflict) X 2 (judgment: positive/negative) ANOVA with repeated measures. No main effect or interaction reached significance (all F < 2.3, all p > 1.3). For mean RTs see Table 1, Appendix.

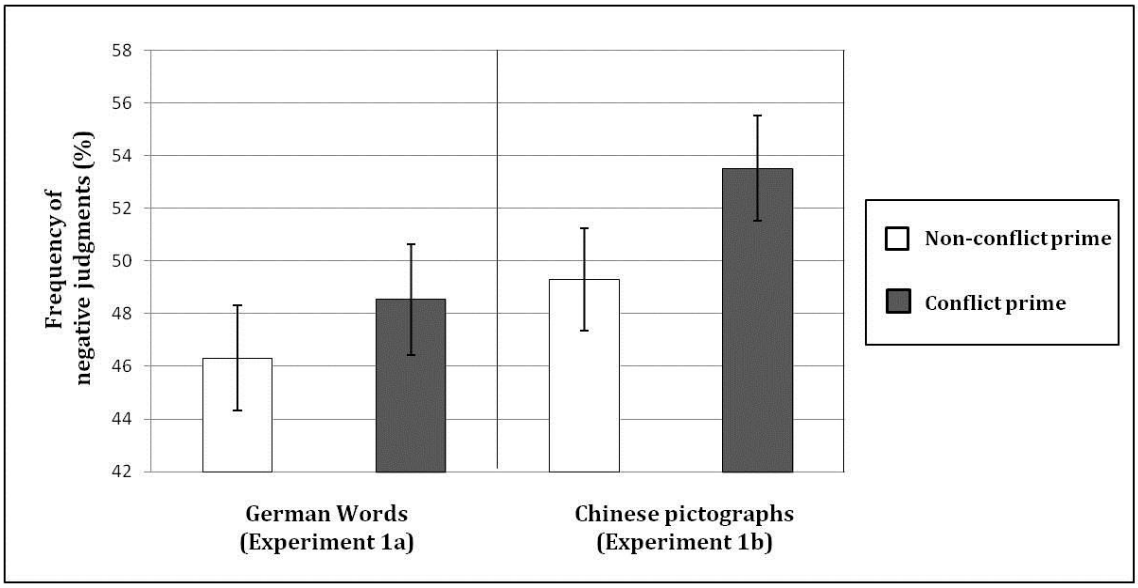

Figure 3. Frequencies (%) of negative judgments of neutral targets as a function of prime condition (non-conflict, conflict) in Experiments 1A and 1B. Bars represent standard errors of the mean.

GENERAL DISCUSSION

The results presented here clearly support the notion of conflicts as aversive signals as implied by the integrative account of ACC function recently suggested by Botvinick (2007). The negative valence of conflicts, just as the negative affect induced by frowning faces (Murphy & Zajonc, 1993) or negative pictures (Payne et al., 1995), spreads to neutral target stimuli which are then evaluated accordingly: Neutral German words (Experiment 1A) and Chinese pictographs (Experiment 1B) were more often judged as negative after conflict as compared to non-conflict primes. Whereas findings of conflict priming in paradigms relying on prime-target-compatibility (Dreisbach & Fischer, 2012a) were ambiguous with regard to their origin (i.e., match vs. mismatch of either *valence* or *processing fluency* between prime and target), the two experiments presented here provide unequivocal evidence for the aversive nature of conflicts.

However, and for the sake of completeness, it should be noted that there exist at least two studies that were not able to find any evidence in favor of the affective valence of conflict stimuli. Schacht and colleagues (Schacht, Nigbur, & Sommer, 2009; Schacht, Dimigen, & Sommer, 2010) registered physiological markers of arousal and emotion in a go/no-go paradigm and found reduced startle blink and skin conductance responses in (conflict) no-go trials as compared to (non-conflict) go trials denoting - if anything - rather reduced arousal and less negative valence for no-go trials. However, go and no-go trials not only differ with respect to their (presumed) affective valence but obviously so also with respect to other processing characteristics (like motor affordances). In contrast, Renaud and Blondin (1997) let participants perform a variation of the Stroop task with equal motor affordances for high and low conflict stimuli while recording their heart rates. More precisely, conflict was manipulated block-wise: Participants performed blocks of either only incongruent or only neutral (colored XXX) trials. The authors found increased heart rates in the conflict (incongruent stimuli) as compared to non-conflict (neutral stimuli) blocks. In the same line, Kobayashi, Yoshino, Takahashi, and Nomura (2007) report enhanced skin conductance responses (SCRs) associated with incongruent trials in a Stroop task. Taken together, the findings of Renaud and Blondin (1997), and Kobayashi et al. (2007) can be taken as evidence for the increased effort associated with conflict stimuli. Higher effort, in turn, is considered to be experienced as aversive (Song & Schwarz, 2008). This is also in line with Hajcak, McDonald, and Simons (2004) who report an association of enhanced heart rate and SCRs with negative affect in response to error conduction. In sum, there is now physiological as well as psychological evidence for the aversive nature of conflicts.

One limitation of the present study rests on the working principle of the affective priming paradigm. In this paradigm, participants do not have to react overtly to the primes. As we used conflict and non-conflict Stroop primes as affective primes in our study, this raises the question if passive viewing of conflict primes indeed induced (response) conflict in the present paradigm. In fact, in the original conflict model as proposed by Botvinick and colleagues, conflict was measured over the response (i.e. output) layer (Botvinick et al., 2001), suggesting that response conflict is actually a mandatory precondition for control adjustments to occur. However, the authors also admitted that in principle, such conflict could occur at any other representational level. More precisely, they state that conflict might be triggered by any ‘‘simultaneous activation of incompatible representations’’ (p. 680). Furthermore, van Veen et al. (2004) point out that conflict monitoring has repeatedly been found *not* to be restricted to the response level. For example, there is evidence for ACC activation for response as well as perceptual and semantic conflict in a global/local task (Weissman, Giesbrecht, Song, Mangun, & Woldorff, 2003) and in the non-response condition of a Stroop task (Milham, Banich, & Barad, 2003). And finally, in our study, it can be assumed that at least preparatory motor processes were present in both experiments. Note that participants had to monitor for events that required motor reactions to Stroop primes (i.e., catch trials). These events were denoted by both the word and color dimension of the primes, that is, together with the finding of a very low number of catch trial omissions, it is very likely that the Stroop primes not only induced stimulus but probably also response conflict. As a side note, the functional boundaries of response and stimulus conflict are still not drawn clearly in the literature – Notebaert and Verguts (2006), for example, found enhanced conflict adaptation effects for stimulus conflict but not for response conflict.

The notion of the ACC as a detector of both cognitive as well as affective conflict has been proposed earlier (Bush, Luu, & Posner, 2000). Interestingly, while Bush et al. (2000) ascribed the cognitive and affective monitoring functions to separate regions of the ACC (dorsal and ventral ACC, respectively), Shackman et al. (2011) argued against this segregated view of ACC function in a recent review. Indeed, the authors presented strong evidence for conjoint anterior midcingulate cortex (mACC) activation by cognitive control, negative affect and pain. This fits perfectly with the idea that this region of the ACC serves the function of an aversive signal detector, as suggested by Botvinick (2007), whose integrative account of ACC function was the starting point for our investigation. The author proposed that two long-standing theories of ACC function, namely the conflict monitoring theory (Botvinick et al., 2001) and the outcome evaluation account (Holroyd & Coles, 2002), might converge on the detection of aversive signals in general. The present results strongly support the notion of the ACC as a detector and indicator of aversive signals. However, given that our conclusions are based entirely on behavioral data, it will be vital to investigate the neural mechanisms underlying conflict priming effect in future studies. More precisely, a consequential assumption that could be tested using functional MRI is, whether and how valence judgments of targets actually covary with the strength of prime-induced ACC activation. Furthermore, assuming that the ACC only *detects* the aversive signal conveyed by a conflict, future studies should elucidate the role of brain regions other than the ACC that are involved in the further processing and generation of the negative judgments after the (aversive) conflict is detected. For instance, it is conceivable that functional connectivity between ACC and affect-related regions (e.g., amygdala, striatum or ventromedial prefrontal cortex) varies as a function of conflict priming.

To conclude, the results of the conflict priming paradigm presented here, together with previous more or less direct evidence, show that conflict indeed is registered as an aversive signal (Dreisbach & Fischer, 2012a; Schouppe et al., 2012; van Steenbergen et al., 2009; 2010). Given the further evidence that aversive stimuli have been shown to induce sequential processing adjustments even in the absence of any response conflict (Dreisbach & Fischer, 2011), it can be assumed that the conflict monitoring theory might actually be applicable to any aversive signal in the ongoing processing stream. Our results thus add to the growing literature showing that affective signals play an important role in sequential action control (see Dreisbach & Fischer, 2012b, for a review).

ACKNOWLEDGEMENTS

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APPENDIX

	Stroop-Primes					
	Conflict		Non-Conflict		Total	
Judgment	**1A**	**1B**	**1A**	**1B**	**1A**	**1B**
Negative	914.3 (306)	796.8 (175.2)	912.8 (287.6)	798.3 (190.1)	913.5 (295.9)	797.6 (178.9)
Positive	897.7 (294.2)	783.7 (179.1)	898.8 (294.2)	771.9 (148.7)	898.2 (285.9)	777.8 (161.3)
Total	905.8 (282.0)	790.2 (173.5)	906.0 (297.1)	785.1 (165.3)		

Table 1. Mean RTs for target judgments in Experiment 1A and 1B as a function of judgment (negative, positive) and prime congruency (conflict, non-conflict; standard deviations in parentheses).

STUDY 2

The Time Course of the Aversive Conflict Signal

Julia Fritz, Gesine Dreisbach

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ABSTRACT

The idea that conflicts are aversive signals recently has gained strong support by both physiological as well as psychological evidence. However, the time course of the aversive signal has not been subject to direct investigation. In the present study, participants had to judge the valence of neutral German words after being primed with conflict or non-conflict Stroop stimuli in three experiments with varying SOA (200 ms, 400 ms, 800 ms) and varying prime presentation time. Conflict priming effects (i.e., increased frequencies of negative judgments after conflict as compared to non-conflict primes) were found for SOAs of 200 ms and 400 ms, but absent (or even reversed) with a SOA of 800 ms. These results imply that the aversiveness of conflicts is evaluated automatically with short SOAs, but is actively counteracted with prolonged prime presentation.

INTRODUCTION

Cognitive control is needed in situations in which automatic, well-learned responses have to be suppressed in favor of controlled, less habitual responses (Miller & Cohen, 2001). In everyday life, such a situation occurs for example when you are visiting a country with left-hand drive but are used right-hand traffic from your home country. When crossing a street in Bali, for example, a German tourist would have to suppress the habitual action of looking left before starting to walk, but instead should look right. In the laboratory, cognitive control is mostly studied using paradigms involving conflicting response tendencies, as conflict is a known trigger for cognitive control processes (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

A prominent conflict task is the Stroop paradigm (Stroop, 1935). Here, participants have to name the ink color of a color word presented in a certain color, that is, they have to suppress the automatic, highly-learned action of reading the depicted word in favor of the controlled action of naming its color. Conflict arises whenever word meaning and word color are incongruent (such as RED printed in blue, for example) as opposed to when they are congruent (such as RED printed in red, for example). Recent theoretical accounts (Botvinick, 2007) as well as physiological (Renauld & Blondin, 1997; Kobayashi, Yoshino, Takahashi, & Nomura, 2007; van Bochove, van der Haegen, Notebaert, & Verguts, 2013; van Steenbergen & Band, 2013) and psychological findings (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013; Schouppe et al., 2012; van Steenbergen, Band, & Hommel, 2009; 2012) suggest that such conflicts are experienced as aversive and that this aversiveness is related to subsequent behavioral adaptations (Botvinick, 2007; for a review, see Dreisbach & Fischer, 2012b). These findings highlight the important role of affect in allegedly “cold” cognition and in action control in general (see Shackman et al., 2011).

In two recent studies (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013), we demonstrated the aversive nature of conflicts by using variants of the affective priming paradigm that was originally introduced by Fazio, Sanbonmatsu, Powell, and Kardes (1986; see also Fazio, 2001) and is used to measure the affective valence of attitude objects. In the original affective priming paradigm, an attitude object (word or picture) is presented as prime stimulus and immediately followed by a positively or negatively valenced target stimulus. Participants’ task is to categorize the valence of the target stimulus as fast and accurate as possible. The typical finding is that a prime that is automatically evaluated as positive eases the evaluation of positive targets and impairs the evaluation of negative targets and vice versa. That is, the affective priming effect is commonly interpreted in terms of automatic attitude activation by the prime, which then facilitates processing of affect-congruent information and impairs processing of affect-incongruent information (Fazio et al., 1986; Fazio, 2001; Hermans, Spruyt, & Eeelen, 2003). Using conflict and non-conflict Stroop stimuli as affective primes, Dreisbach and Fischer (2012) showed that Stroop conflict primes, as compared to Stroop non-conflict primes, lead to faster categorization of negative target words and pictures, thereby providing first direct evidence for the aversiveness of conflict stimuli.

In order to exclude possible confounds by processing fluency we recently chose a slightly different variant of the affective priming paradigm (for a detailed discussion see Fritz & Dreisbach, 2013). There, we let participants judge the valence of *neutral* German words (Experiment 1A) and Chinese pictographs (Experiment 1B) that were always preceded by conflict or non-conflict Stroop stimuli. In both experiments, we consistently found that Stroop conflict primes (as compared to Stroop non-conflict primes) increased subsequent negative judgments of neutral target stimuli. Again, this supports the notion that conflicts, as compared to non-conflicts, inherit aversiveness, and that this aversiveness influences subsequent behavior (i.e., the judgment of neutral stimuli in that study). However, there are still many unknowns when it comes to the exact nature, function and boundary conditions of the aversive signals elicited by conflict stimuli. This study aims to elucidate specifically the temporal dynamics of the aversive nature of conflict stimuli.

Typically, affective priming is observed with short stimulus onset asynchronies (SOAs, i.e., the time interval between the onset of the prime and the onset of the target stimulus) of 300 ms or less but is not found with longer SOAs (Avero & Cavo, 2006; De Houwer, Hermans, & Eelen, 1998; Fazio et al., 1986; Hermans, De Houwer, & Eelen, 1994; 2001; Hermans, et al., 2003; Klauer, Roßnagel, & Musch, 1997). For two reasons, this has been taken as evidence that the affective evaluation of a stimulus and the generation of object attitudes is a highly automatic process (Fazio et al., 1986; see Hermans et al., 2001). First, it has been argued that SOAs of 300 ms or less are too short to evoke conscious expectancies or controlled response strategies. And second, if affective priming effects were a result of *controlled* processes, then these effects should become even stronger (or be at least just as strong) with increasing SOAs because controlled processes are more time consuming than automatic processes. This, however, is not the case: Affective priming effects typically *decrease* with increasing SOA (e.g., De Houwer et al., 1998).

So far, the time course of affective priming has been studied mainly by using words (e.g., De Houwer et al., 1998; Fazio et al., 1986; Hermans et al., 1994; 2001; Klauer et al., 1997) or pictures (e.g., Avero & Calvo, 2006; Hermans et al., 1994; 2003) as primes, respectively. The question that we are interested in is whether the aversive conflict signal, as measured previously (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013), is also a result of an automatic evaluation process or a consequence of a controlled evaluation process. After all, there is a lot of evidence in the literature that conflict stimuli trigger processes of cognitive control (e.g., Botvinick et al., 2001; Kerns et al., 2004). And the SOA of 400 ms in our previous studies does not really allow drawing any strong conclusions with respect to the automaticity of the evaluation process because 400 ms might just be at the border from automatic to controlled processing. Therefore, in the present study, we again used an affective priming paradigm (see Fritz & Dreisbach, 2013) but this time varied SOAs in three steps of 200 ms, 400 ms and 800 ms, respectively. For the 400 ms SOA, we expected to replicate previous results (more negative evaluations following conflict as compared to non-conflict primes). Priming effects for the other two SOAs will then be indicative of the level of automaticity of the conflict priming effect. Conflict priming as a result of an automatic evaluation should result in a priming effect already after 200 ms and be reduced or even absent with a SOA of 800 ms. Conversely, if conflict priming results from a controlled evaluation process it should increase with increasing SOA and thus even be stronger with a SOA of 800 ms.

EXPERIMENT 2A

Method

Participants

Eighty-eight students (mean age: 22.0, *SD* = 2.3; 62 female, 26 male) from the University of Regensburg participated in exchange for partial course credit or payment (3 Euros). 4 left-handers who participated without meeting requirements (being right-handed), 6 participants who showed a strong valence bias (more than 75% of judgments in either valence), 2 participants who had difficulties in a color identification test and 4 participants who had exceptionally high error rates in catch trials (more than 25%) were excluded, leaving a final sample of 72 participants (24 participants per *SOA* condition).

Material

The German color words for RED, GREEN, BLUE, YELLOW, and PURPLE (ROT, GRÜN, BLAU, GELB, LILA) printed in red, green, blue, yellow, or purple served as primes. If color word and word color matched (such as RED printed in red, for example), the prime was a *non-conflict prime*; if color word and word color mismatched (such as RED printed in blue, for example), the prime was a *conflict prime*. Targets were 138 German words (109 nouns, 18 verbs, and 11 adjectives selected on the basis of neutral affective ratings from the Berlin affective word-list reloaded BAWL-R (mean valence ratings: -.00, running on a scale from 3 (very negative) through 0 (neutral) to 3 (very positive), SD = .00; range of ratings: .109; Võ et al., 2009). Primes and targets were written in Arial bold (26 pt), subtending a visual angle of 0.8° X 0.8° at a viewing distance of 55 cm and were presented centrally on a light grey background.

Procedure

Participants' task was to judge the valence of neutral German words that were preceded by non-conflict or conflict Stroop primes. Positive judgments had to be indicated by a right key press, negative judgments by a left key press ('-' and 'y' on a QWERTZ-keyboard, respectively). This assignment was held constant as people have a natural bias to associate positive concepts with their dominant body side (i.e., the right side in a right-hander sample; Cassasanto, 2009; see also Dreisbach & Fischer, 2012a; Fritz &

Dreisbach, 2013). Participants were instructed to choose each key at approximately the same rate. By that, we tried to minimize potential response biases. In order to ensure the processing of the Stroop primes, we interspersed catch trials in the experiment: Whenever the prime entailed the color word PURPLE or another color word was printed in purple, participants did not have to judge the subsequently presented target but had to press the space bar as fast as possible instead. By that, participants had to encode both the color and word dimension of the Stroop primes properly and thus a conflict experience in conflict primes was warranted.

Trials started with the presentation of a fixation cross for 250 ms, followed by a (conflict or non-conflict) Stroop prime. Depending on the stimulus onset asynchrony (SOA), the Stroop primes were either presented for 200 ms (SOA 200 ms) or 400 ms (SOA 400 ms and SOA 800 ms). In the SOA 800 ms condition, an additional blank screen was presented for 400 ms after the Stroop primes. Immediately after the respective SOA, the target was presented until participants' response. After an inter-trial-interval (ITI) of 1000 ms length a new trial started. In the case of an error (if participants missed a catch trial or wrongly identified a regular Stroop prime as a catch trial), the ITI was prolonged to 2500 ms and the German word for ERROR (FEHLER) appeared on screen. For schematic trial sequences depending on SOA condition see also Figure 4.

After a short test to exclude color blindness, the experiment started with two short practice blocks of 24 trials length to familiarize participants with the task. After that, an experimental block of 114 trials followed. In this block, 48 non-conflict, 48 conflict, and 18 catch primes were followed randomly by one of the 114 neutral target words none of which had been used in the practice blocks. Trials were presented in random order for each subject. The experiment lasted about 6 minutes (SOA 200 ms), 7 minutes (SOA 400 ms) or 8 minutes (SOA 800 ms), respectively.

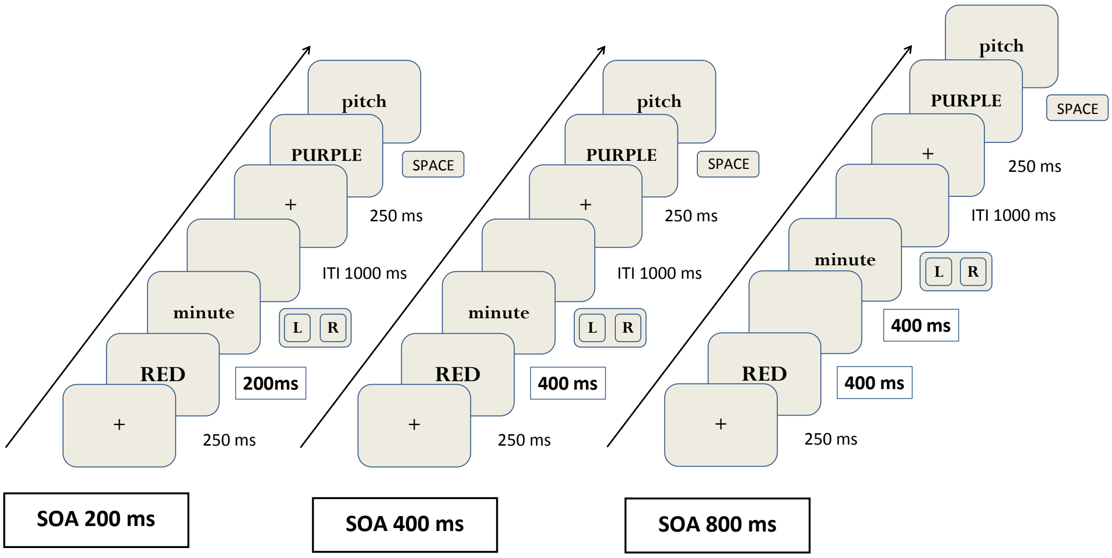

Figure 4. Trial sequences for correct trials in SOA conditions 200 ms, 400 ms and 800 ms, respectively.

Design

A 3 (SOA: 200 ms vs. 400 ms vs. 800 ms) X 2 (Prime Condition: non-conflict vs. conflict) mixed factors design was applied. *SOA* was manipulated between participants to be able to present each neutral target word only once per participant. By this we aimed to avoid a possible mere exposure effect (for a review see Bornstein, 1989) which might have caused a positivity bias (but see Klauer, Teige-Mocigemba, & Voss, 2009). *Prime Condition* was manipulated within participants.

Results and Discussion

Mean error rate in catch trials did not differ between *SOA* groups, $F(2, 69) < 1$, $p > .56$, and was low (6 %, $SD = .3$ %), suggesting that participants properly encoded both word and color dimension of the Stroop primes. To test for a general valence bias in judgments, we computed mean frequencies of negative judgments for correct trials for each subject. As frequency of negative judgments did not differ between *SOA* conditions, $F(2, 69) < 1$, $p > .93$, we conducted a one-sampled t-test against the null hypothesis of 50% negative judgments over all SOA conditions. Results show that participants evaluated the words rather positive (44% negative judgments, *SD* = 8 %, *t* (71) = 5.83, *p* < .001, Cohen's *d* = 1.38).

To test for conflict priming, we computed mean frequencies of negative judgments for correct trials for each prime condition and each subject separately and conducted a 3 X 2 – mixed factors ANOVA with the between factor *SOA* (200 ms, 400 ms, 800 ms) and the within factor *Prime Condition* (non-conflict, conflict). There was a significant main effect of *Prime Condition*, *F* (1, 69) = 6.19, *p* < .05, η^2 = .08, which was further modulated by *SOA*, *F* (2, 69) = 3.82, *p* < .05, η^2 = .1. Pairwise t-tests revealed that participants judged neutral German words more frequently as negative after conflict as compared to non-conflict primes when the SOA between prime and target onset was 200 ms (48 % vs. 42 %, respectively; *t* (23) = 2.15, *p* = .04, Cohen's *d* =1.62) and when the SOA was 400 ms (47 % vs. 40 %, respectively; *t* (23) = 3.42, *p* = .00, Cohen's *d* =1.24), but not for a SOA of 800 ms (44 % vs. 45 %, respectively; *t* (23) < 1, *p* = .47). Further post-hoc analyses showed that there was no difference in the conflict priming effect between SOA conditions 200 ms and 400 ms, *F*(1, 46) < 1, *p* > .73, but that the conflict priming effect differed significantly between conditions 800 ms and 200 ms and between conditions 800 ms and 400 ms (*F*(1, 46) = 6.76, *p* < .05, η^2 = .13 and *F*(1, 46) = 4.02, *p* = .05, η^2 = .08, respectively; see Figure 5).

Mean reaction times (RT) for each prime-target combination of each SOA condition were entered into a 3 X 2 X 2 – mixed factors ANOVA with the between factor *SOA* (200 ms, 400 ms, 800 ms) and the within factors *Prime Condition* (non-conflict, conflict) and *Judgment* (negative, positive). The main effect of *Judgment* was significant, *F*(1, 71) = 9.69, *p* < .01, η^2 = .12. RTs were faster for positive as compared to negative judgments (1035.6 ms vs. 1090.91 ms, respectively). No further main effects or interactions approached significance (all *F* < 1.32, all *p* > .27). For mean RTs see Table 2, Appendix.

The data of Experiment 2A replicate our earlier findings of conflict priming (i.e., increased negative judgments of neutral words) with a SOA of 400 ms (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013). Furthermore, conflict priming is still present when reducing the SOA to 200 ms, but is absent when increasing the SOA to 800 ms. This suggests that conflict priming is a rapid, automatic process as opposed to a rather slow, controlled process.

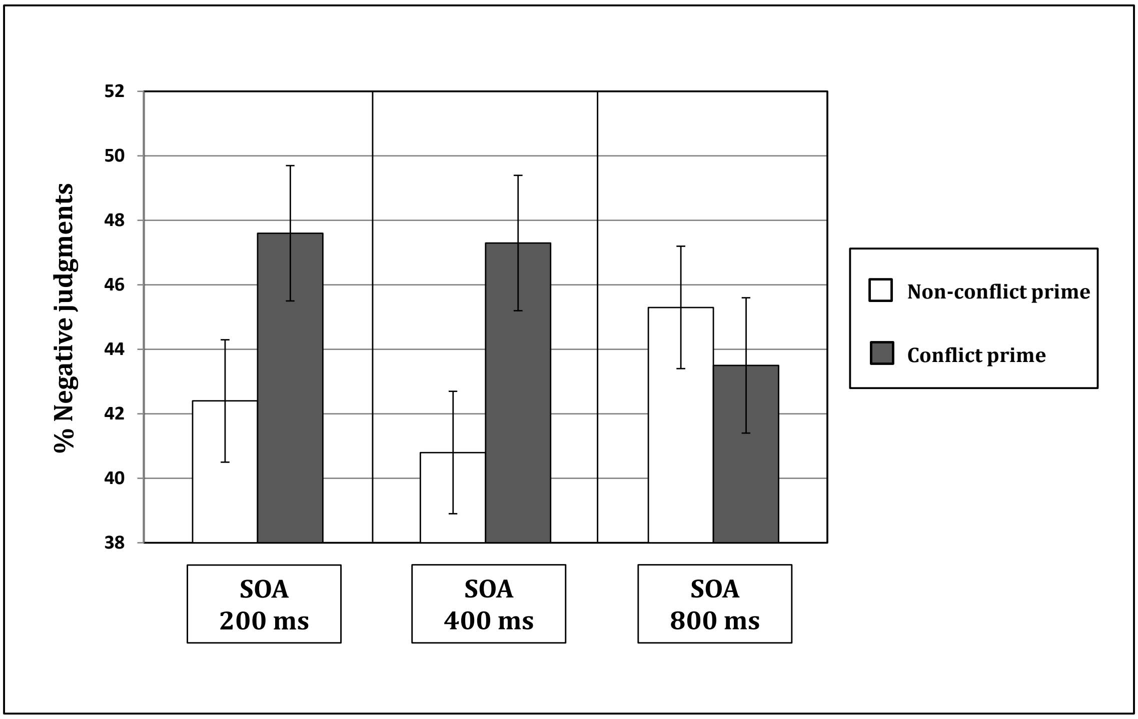

Figure 5. Negative judgments (%) of neutral targets as a function of Prime Condition (non-conflict prime, conflict prime) and Stimulus Onset Asynchrony (SOA: 200 ms, 400 ms, 800 ms) in Experiment 2A. Error bars represent standard errors of the mean.

However, in Experiment 2A, there were two possible confounds that might call our interpretation into question. First, in Experiment 2A, SOA was confounded with the prime's presentation duration. Prime duration was 200 ms in the SOA 200 ms condition, but 400 ms in the SOA 400 ms and SOA 800 ms conditions. Second, catch trials were always incongruent in Experiment 2A, which might have increased the aversiveness of incongruent primes by rendering congruent primes as safety signals (because congruency signaled NO catch prime). In order to eliminate these shortcomings, we included incongruent as well as congruent catch trials in the second experiment and presented the primes for 200 ms in all SOA conditions.

EXPERIMENT 2B

Method

Participants

One hundred and ten students (mean age: 22.0, *SD* = 4.2; 92 female, 18 male) from the University of Regensburg participated in exchange for partial course credit or payment (2 Euros). 5 participants who showed a strong valence bias (more than 75% of judgments in either valence), 2 participants who had difficulties in a color identification test, 9 participants who had exceptionally high error rates in catch trials (more than 25%) and 4 participants who kept asking for instructions during the experiment[15] were excluded, leaving a final sample of 90 participants (30 participants per *SOA* condition)[16].

Material and Procedure

Material and Procedure of Experiment 2B was identical to Experiment 2A, with two exceptions. First, half of the 18 catch trials were congruent (that is, PURPLE printed in purple). The other half was incongruent, that is, each participant was presented with 9 randomly chosen catch trials that consisted of either the word PURPLE printed in red, yellow, green, or blue, or the words RED, YELLOW, GREEN, or BLUE printed in purple, drawn with replacement. Second, the Stroop primes were presented for 200 ms in each of the three SOA conditions. Thus, in the SOA 400 ms condition the prime was followed by a blank screen for 200 ms; and in the SOA 800 ms condition, the prime was followed by a blank screen for 600 ms.

Design

A 3 (SOA: 200 ms vs. 400 ms vs. 800 ms) X 2 (Prime Condition: non-conflict vs. conflict) mixed factors design was applied. *SOA* was manipulated between participants, *Prime Condition* was manipulated within participants.

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[15] These four participants kept asking questions during the experiment how fast they should press the space bar in response to the catch trials, and/or whether they still had to judge the valence of the target words following a catch trial.

[16] The interaction Prime condition by SOA, found in Experiment 2A, was not significant after N=60 in Experiment 2B. To make sure that this null effect was not due to a lack of power, we decided to add 10 participants in each SOA condition.

Results and Discussion

Mean error rate in catch trials was low (6 %, *SD* = .3 %), suggesting that participants properly encoded both word and color dimension of the Stroop primes. Furthermore, mean error rate in catch trials did marginally differ between *SOA* groups, *F* (2, 87) = 2.57, *p* = .08, η^2 = .06. *T*-tests (two-sided) revealed that participants missed the catch trials more often in the 400 ms (9 %, *SD* = 7 %) than in the 800 ms condition (5 %, *SD* = 7 %), *t* (58) = 2.02, *p* < .05, Cohen's *d* = 0.53, while catch trial error frequencies did not differ between the 200 ms condition (6 %, *SD* = 5 %) and both the 400 ms and 800 ms conditions, both t's < 1.64, both p's > .11. To test for a general valence bias in judgments, we computed mean frequencies of negative judgments for correct trials for each subject. As frequency of negative judgments did not differ between *SOA* conditions, *F* (2, 87) < 1, *p* = .47, we conducted a one-sampled t-test against the null hypothesis of 50% negative judgments over all SOA conditions. Results show that participants evaluated the words rather positive (45% negative judgments, *SD* = .1 %, *t* (89) = 5.98, *p* < .001).

To test for conflict priming, we computed mean frequencies of negative judgments for correct trials for each prime condition and each subject separately and conducted a 3 X 2 – mixed factors ANOVA with the between factor *SOA* (200 ms, 400 ms, 800 ms) and the within factor *Prime Condition* (non-conflict, conflict). There was a significant main effect of *Prime Condition*, *F* (1, 89) = 5.72, *p* < .05, η^2 = .06, which was however not further modulated by *SOA*, *F* < 1, *p* > .05. Participants judged neutral German words more frequently as negative after conflict as compared to non-conflict primes (46 % vs. 43 %, respectively; see Figure 6).

Again, mean reaction times (RT) for each prime-target combination of each SOA condition were entered into a 3 X 2 X 2 – mixed factors ANOVA with the between factor *SOA* (200 ms, 400 ms, 800 ms) and the within factors *Prime Condition* (non-conflict, conflict) and *Judgment* (positive, negative). The main effect of *Judgment* was significant, *F* (1, 87) = 9.22, *p* < .01, η^2 = .09. RTs were faster for positive as compared to negative judgments (1088.86 ms vs. 1124.30 ms, respectively). The main effect of *Prime Condition* was significant, *F* (1, 87) = 15.63, *p* < .001, η^2 = .15. RTs were faster after non-conflict as compared to conflict primes (1079.55 ms vs. 1133.61 ms, respectively). No further main effect or interaction was significant, all *F*'s < 2.51, all *p*'s >.12. For mean RTs see Table 3, Appendix.

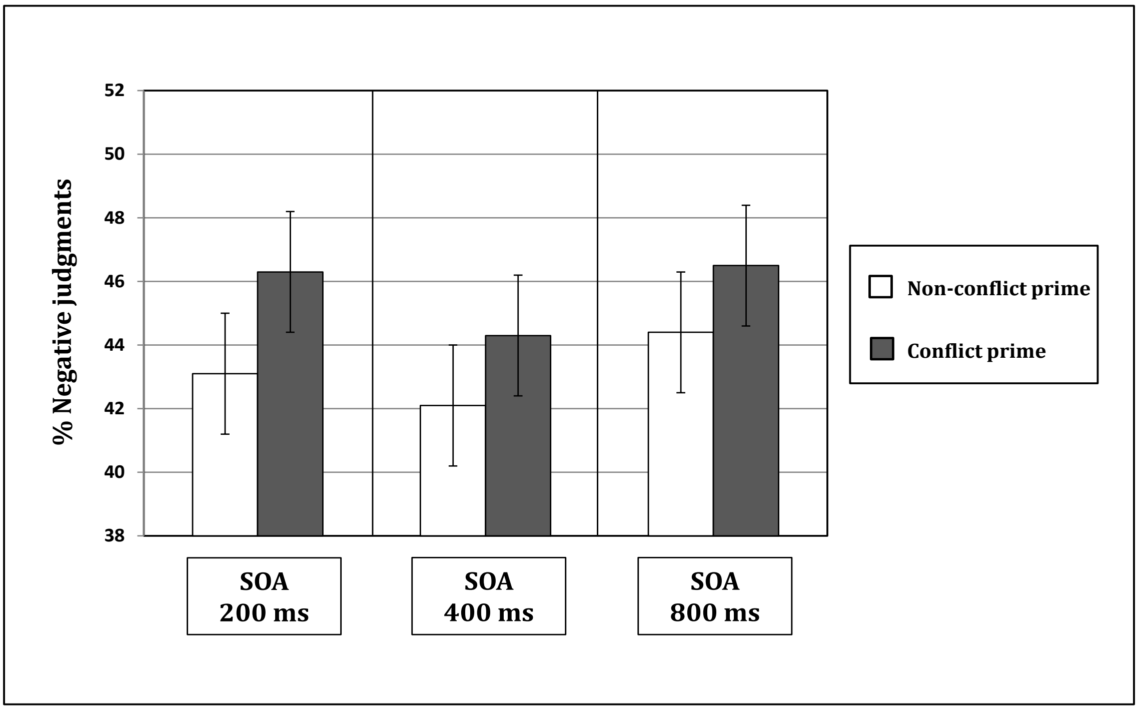

Figure 6. Negative judgments (%) of neutral targets as a function of Prime Condition (non-conflict prime, conflict prime) and Stimulus Onset Asynchrony (SOA; 200 ms, 400 ms, 800 ms) in Experiment 2B. Error bars represent standard errors of the mean.

The results from Experiment 2B do not support the idea that conflict priming effects found in Experiment 2A can be explained by a catch trial-congruency-confound. Although prime congruency did no longer predict the absence of a catch trial (such that non-conflict primes no longer served as safety signal and conflict primes did not cause arousal by means of association), participants still judged neutral German words more frequently as negative after conflict as compared to non-conflict primes. This is also in line with the study by Dreisbach and Fischer (2012), where conflict priming was found and no catch primes were included in the first place. The overall smaller effect size of the priming effect in Experiment 2 as compared to Experiment 2A might indicate that the catch trial-congruency confound added to the conflict priming effect in Experiment 2A and/or that passive decay during the interval between prime presentation and target presentation reduced the conflict priming effect in Experiment 2B. Taken together, the results suggest that conflicts are in fact inherently aversive. This aversiveness influences the processing of subsequently presented information, i.e., the neutral German words.

Interestingly and in contrast to Experiment 2A, conflict priming did not interact with SOA in Experiment 2B. It seems that with a longer SOA (800 ms), conflict priming not only depends on the SOA but also on the prime's presentation duration: Conflict priming with a SOA of 800 ms is observed with a presentation duration of 200 ms (Experiment 2B), but is absent with a presentation duration of 400 ms (Experiment 2A). While in Experiment 2A, the absence of conflict priming could be explained by *either* passive decay of the affective valence with time *or* active counter-regulation of the cognitive system, the additional results of Experiment 2B might serve as a first hint that both, passive decay and active counter-regulation are involved. Whereas passive decay should predominantly occur during the interval (i.e., the blank screen) between prime presentation and target onset, active counter-regulation should increase with increasing prime duration. Even though comparisons between experiments should be treated with caution[17], the overall smaller effect size of the priming effect in Experiment 2B as compared to Experiment 2A might be taken as evidence for passive decay during the interval between prime presentation and target presentation. At the same time, the comparison between SOA 800 conditions of Experiment 2A and 2B might be taken as a first hint for active counter-regulation with increasing prime duration.

In order to gain more direct support for the hypothesis that active counter-regulation depends on the prime's presentation duration, we ran a third experiment, this time presenting the prime for the entire SOA of 800 ms. If counter-regulation indeed increases with increasing prime duration, then conflict priming should be reversed in Experiment 2C.

EXPERIMENT 2C

Method

Participants

Twenty-four students (mean age: 24, *SD* = 3.4; 19 female, 5 male; 7 left-handed, 17 right-handed) from the University of Regensburg participated in exchange for partial course credit or payment (2 Euros). 2 participants who showed a strong valence bias (more than

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[17] The comparison of Experiments 2A, 2B and 2C needs to be done with caution. In Experiment 2A, 20 participants were tested per condition and primes were presented for 200 ms in the 200 ms condition and 400 ms in the 400 ms and 800 ms conditions; furthermore, catch trials were incongruent only. In Experiment 2B, 30 participants were tested per condition and primes were presented for 200 ms in all conditions; here, catch trials could be congruent or incongruent. In Experiment 2C, 20 participants were tested and primes were presented for 800 ms; here, catch trials again could be congruent or incongruent.

75% of judgments in either valence), 1 participant who was talkative during the experiment and 1 participant who had exceptionally high error rates in catch trials (more than 25%) were excluded, leaving a final sample of 20 participants.

Material and Procedure

Material and Procedure of Experiment 2C was identical to Experiment 2B, with the exception that the Stroop primes were now presented for 800 ms and there was consequently no blank screen between prime and target.

Results and Discussion

Mean error rate in catch trials was low (4%, *SD* = .2%), suggesting that participants properly encoded both word and color dimension of the Stroop primes. To test for a general valence bias in judgments, we computed mean frequencies of negative judgments for correct trials for each subject and conducted a one-sampled t-test against the null hypothesis of 50% negative judgments. Results show that participants evaluated the words rather positive (43% negative judgments, *SD* = .1%, t (19) = 3.38, $p < .01$).

To test for conflict priming, we computed mean frequencies of negative judgments for correct trials for each prime condition (non-conflict, conflict) and each subject separately and conducted a two-sided t-test. There was a significant effect of Prime Condition, $t(19) = 2.61$, $p < .05$, Cohen’s $d = .43$. Participants judged neutral words more often as negative after *non-conflict* as compared to after conflict primes (45 % vs. 41 %, respectively). Mean reaction times (RT) for each prime-target combination were entered into a 2 X 2 – ANOVA with the within factors *Prime Condition* (non-conflict, conflict) and *Judgment* (negative, positive). No main effect or interaction was significant, all F’s < 2.49, all p’s >.102. For mean RTs see Table 4, Appendix.

Results of Experiment 2C are clear-cut. Increasing the prime duration to 800 ms and reducing the blank between prime and target to zero lead to a significant reversal: neutral target words were now judged significantly *less* negative following conflict primes as compared to non-conflict primes. This result cannot be explained by passive decay (which should only have assimilated the frequency of negative judgments following conflict and non-conflict primes) but is strongly suggestive of an active counter-regulation process in response to aversive conflict primes.

GENERAL DISCUSSION

The aim of this study was to investigate the time course of the conflict signal in order to elucidate the automaticity of the underlying evaluation processes. In three experiments, participants had to judge the valence of neutral German words that were always preceded by congruent or incongruent Stroop primes. In Experiment 2A, the SOA was set to 200 ms, 400 ms or 800 ms (with prime presentation times of 200 ms, 400 ms and 400 ms, respectively). As predicted, conflict priming (i.e., increased frequency of negative judgments after conflict as compared to non-conflict Stroop primes) was present for SOAs of 200 ms and 400 ms, but was completely absent and descriptively even reversed with a SOA of 800 ms. Thus, results of Experiment 2A replicate prior findings of conflict aversiveness with a SOA of 400 ms (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013), and further show that the aversive quality of conflicts is present already 200 ms after stimulus onset and that it has disappeared 800 ms after stimulus onset. The finding that affective priming with Stroop primes is present with short SOAs but absent with longer SOAs suggests that conflict priming effects are due to the automatic evaluation of Stroop conflicts and not a result of controlled evaluation processes. Our results are also in line with findings from a recent study by Aarts, De Houwer, and Pourtois (2012). There, participants performed an error priming study similar to the conflict priming paradigm used in our work with the difference that participants were primed with their self-generated actions. In particular, participants had to judge the valence of positive and negative target words right after correct responses or errors in a Go/No-Go task. That is, accuracy of the preceding response served as a prime for the following affective target evaluation. In three experiments, the authors also manipulated the interval between the error or correct response and target word onset (300 ms, 600 ms and 1000 ms). Consistent with our findings and the interpretation of an error as an instance of conflict between the *actual* response and a *post-error* correcting response (Botvinick et al., 2001; but see e.g. Holroyd & Coles, 2002, for a different account on error monitoring processes), Aarts et al. (2012) found faster RTs for valence congruent as compared to valence incongruent prime-target combinations. That is, they found faster categorization of negative targets after errors as compared to after correct responses and faster categorization of positive targets after correct responses as compared to after errors. Moreover, and in line with the results presented here, this priming effect was only found in the two short SOAs, i.e., in the 300 ms and 600 ms condition, but not for the long SOA of 1000 ms, strengthening the idea of automatic evaluation of conflict aversiveness.

In Experiment 2B, a possible influence of a catch trial – congruency confound in Experiment 2A (where only incongruent catch primes were included, possibly rendering congruency as safety signal) was ruled out by including incongruent *and* congruent catch trials. Again, participants judged neutral targets more often as negative after conflict as compared to non-conflict primes. Furthermore, prime presentation time was set to 200 ms in all three SOA conditions of Experiment 2B. In contrast to Experiment 2A, conflict priming did no longer interact with SOA, an effect primarily driven by the conflict priming-effect in the 800 ms SOA condition (which had been descriptively reversed in Experiment 2A). Together with the finding of Experiment 2C, where the prime presentation of 800 ms significantly reversed the conflict-priming effect, resulting in more positive judgments following conflict as compared to non-conflict primes, our results suggest that prime duration increases affective counter-regulation. The SOA 800 ms conditions over all three experiments show that conflict priming decreased with increasing prime duration (see Figure 7). These results speak against a pure passive decay explanation with a SOA of 800 ms. Instead, it seems that with a long SOA, longer prime presentation leads to the initiation of an active counter-regulation process (cf. Rothermund, Voss, & Wentura, 2008) that counteracts the negative affect associated with conflicts by inducing a positive processing bias. The observation that this reversed priming effect was only found for a prime presentation of 800 ms suggests that the presumably resource-consuming counter-regulation process is only active in the face of persisting conflict stimulation. Thus, our study is the first to show that the trial-wise presentation of conflict stimuli induces negative affective-motivational states that elicit processes of affective counter-regulation when presented long enough (see also Rothermund, 2003, for a demonstration of feedback-induced affective counter-regulation on a single trial level).

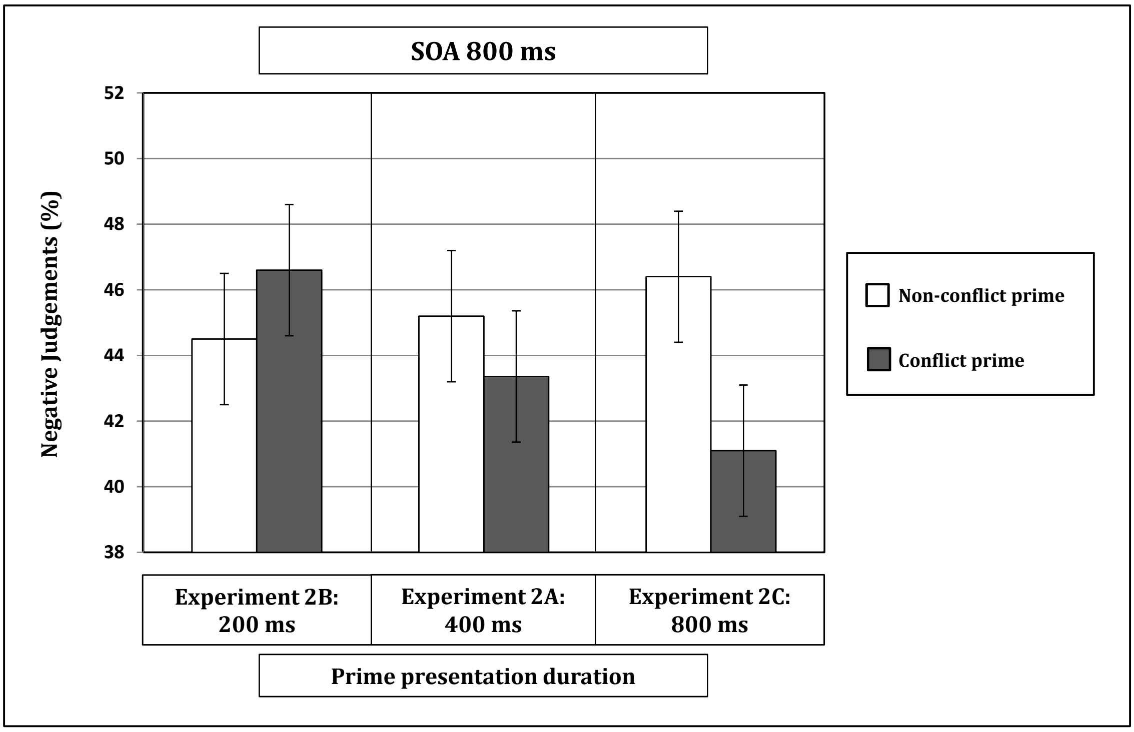

Figure 7. Negative judgments (%) of neutral targets as a function of Prime Condition (non-conflict prime, conflict prime) and Prime presentation duration (200 ms, 400 ms, and 800 ms) in the SOA 800 ms conditions of Experiments 2A, 2B and 2C. Error bars represent standard errors of the mean.

To conclude, the results of this study replicate earlier findings of conflict aversiveness at a SOA of 400 ms (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013) and show that Stroop conflict stimuli are experienced as aversive as soon as 200 ms after stimulus onset. Furthermore, our results are in line with findings that with long SOAs, the cognitive system works in a more controlled processing mode that opposes automatic affective priming effects (e.g., De Houwer et al., 1998). This interpretation offers a bridge to the conflict monitoring account (Botvinick et al., 2001) which postulates that conflict triggers the mobilization of cognitive control. So far, these control processes have only been measured and interpreted in terms of sequential *action* regulation, they might however also represent an instantiation of *affect* regulation. From this perspective, cognitive conflicts would not only trigger processing adjustments as evidenced by reduced response interference in trials following conflict trials (e.g., Botvinick et al, 2001), but also trigger control processes to down-regulate the aversive experience of conflicts (e.g., Rothermund, 2011). This, again, would further support the notion that presumably “cold” cognitive and “hot” emotional processes actually share common grounds (see e.g. Shackman et al., 2011).

In conclusion, the results of this study replicate earlier findings of conflict aversiveness at a SOA of 400 ms (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013) and show that Stroop conflict stimuli are experienced as aversive as soon as 200 ms after stimulus onset. Furthermore, the persisting presence of a conflict stimulus for 800 ms resulted in a significant reversal of the conflict priming effect suggesting a conflict-triggered process of affective counter-regulation.

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APPENDIX

	SOA condition							
	200 ms		*400 ms*		*800 ms*		**Total**	
	Conflict prime	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***
Negative Judgment	1086.42 (390.01)	1064.31 (384.45)	1184.30 (473.83)	1140.38 (461.07)	1046.42 (310.86)	1034.19 (313.38)	1099.04 (396.99)	1079.63 (388.05)
Positive Judgment	1056.43 (367.19)	999.1 (332.9)	1105.22 (406.61)	1094.96 (456.01)	964.19 (282.74)	994.75 (337.87)	1041.95 (355.81)	1029.61 (377.38)
Total	1066.92 (372.85)	1024.72 (348.04)	1140.50 (436.91)	1108.84 (453.49)	990.22 (290.01)	1010.01 (318.37)	1065.88 (371.4)	1047.86 (374.99)

Table 2. Mean RTs for target judgments in SOA conditions 200 ms, 400 ms, and 800 ms as a function of Prime Condition (conflict prime, non-conflict prime) and Judgment (negative, positive) in Experiment 2A (standard deviations in parantheses).

	SOA condition							
	200 ms		***400 ms***		***800 ms***		**Total**	
	Conflict prime	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***	***Conflict prime***	***Non-conflict prime***
Negative Judgment	1232.01 (528.87)	1146.49 (480.68)	1110.2 (264.6)	1057.80 (245.52)	1140.67 (419.33)	1058.66 (399.08)	1160.96 (417.08)	1087.65 (385.46)
Positive Judgment	1148.95 (435.51)	1110.51 (507.44)	1073.74 (257.09)	1016.43 (245.85)	1096.09 (368.3)	1087.44 (385.13)	1106.26 (358.53)	1071.46 (391.85)
Total	1190.48 (472.01)	1128.5 (488.23)	1092.0 (239.88)	1037.12 (239.88)	1118.39 (389.01)	1073.05 (381.37)	1133.61 (379.86)	1079.55 (381.86)

Table 3. Mean RTs for target judgments in SOA conditions 200 ms, 400 ms, and 800 ms as a function of Prime Condition (conflict prime, non-conflict prime) and Judgment (negative, positive) in Experiment 2B (standard deviations in parantheses).

	Conflict prime	***Non-conflict prime***	**Total**
Negative Judgment	1124.17 (180.36)	1162.38 (267.87)	1143.27 (216.51)
Positive Judgment	1141.07 (245.65)	1104.99 (216.55)	1123.03 (223.18)
Total	1132.62 (205.57)	1133.68 (236.83)	1133.15 (226.55)

Table 4. Mean RTs for target judgments as a function of Prime Condition (conflict prime, non-conflict prime) and Judgment (negative, positive) in Experiment 2C (standard deviations in parantheses).

STUDY 3

The Influence of Negative Stimulus Features on Conflict Adaption: Evidence from Fluency of Processing

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ABSTRACT

Cognitive control enables adaptive behavior in a dynamically changing environment. In this context, one prominent adaptation effect is the sequential conflict adjustment, i.e. the observation of reduced response interference on trials following conflict trials. Increasing evidence suggests that such response conflicts are registered as aversive signals. So far, however, the functional role of this aversive signal for conflict adaptation to occur has not been put to test directly. In two experiments, the affective valence of conflict stimuli was manipulated by fluency of processing (stimulus contrast). Experiment 1 used a flanker interference task, Experiment 2 a color-word Stroop task. In both experiments, conflict adaptation effects were only present in fluent, but absent in disfluent trials. Results thus speak against the simple idea that any aversive stimulus feature is suited to promote specific conflict adjustments. Two alternative but not mutually exclusive accounts, namely resource competition and adaptation-by-motivation, will be discussed.

INTRODUCTION

In an environment full of tempting opportunities and action affordances, appropriate action selection is a constant challenge. For example, grabbing the low fat yogurt instead of the rich but more delicious chocolate mousse from the fridge can be a hard decision. In situations like this, cognitive control supports the selection of the weaker but intended action in the face of a stronger but inadequate action (c.f. Miller & Cohen, 2001). Moreover, when confronted with response conflicts, cognitive control not only enables conflict resolution in the current trial but also adjusts processing parameters such that the cognitive system is better prepared when the response conflict repeats as indicated by reduced response interference in post-conflict trials (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Caessens, Notebaert, Burle, & Soetens, 2005; Egner, 2008; Gratton, Coles, & Donchin, 1992; Notebaert, Soetens, & Melis, 2001; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr & Kunde, 2008). On a neuronal level, it has been suggested that it is the anterior cingulate cortex (ACC) that detects conflicts and sends this information to the dorsolateral prefrontal cortex which then increases control in the post-conflict trial (e.g., Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004).

In the past decade, huge advances have been made to further our understanding of the underlying processes that enable such dynamic control adaptations (for recent approaches to conflict adaptation effects see for example Braem et al., 2014; Duthoo et al., 2014; Jiang, Heller, & Egner, 2014). Questions of interest concerned the locus and specificity of the adaptation effect (e.g., Kiesel, Kunde & Hoffmann, 2006; Kunde & Wühr, 2006; Notebaert & Verguts, 2008; Wendt, Luna-Rodriguez & Jacobsen, 2012), the role of episodic retrieval and priming processes (e.g., Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003), the role of learning (e.g., Blais, Robidoux, Risko, & Besner, 2007; Blais & Verguts, 2012; Holroyd & Coles, 2002; Verguts & Notebaert, 2009), timing (e.g., Goschke & Dreisbach, 2008; Pastötter, Dreisbach & Bäuml, 2013; Scherbaum, Fischer, Dshemuchadse, & Goschke, 2011), conflict strength (e.g., Forster, Carter, Cohen, & Cho, 2011; Takezawa & Miyatani, 2005; Wendt, Kiesel, Gehringswald, Purmann, & Fischer, 2014), working memory load (Fischer, Plessow, Kunde, & Kiesel, 2010; Soutschek, Strobach, & Schubert, 2012;

Stürmer, Seiss, & Leuthold, 2005), and context effects in general (e.g. Fischer, Dreisbach, & Goschke, 2008; Funes, Lupianez, & Humphreys, 2010).

Only recently, the question of how stress, affect and motivation might influence processing adjustments has moved into the focus of research (e.g. Braem, Verguts, Roggeman, & Notebaert, 2012; Kuhbandner & Zehetleitner, 2011; Padmala, Bauer, & Pessoa, 2011; Plessow, Fischer, Kirschbaum, & Goschke, 2011; Stürmer, Nigbur, Schacht, & Sommer, 2011; van Steenbergen, Band, & Hommel, 2009, 2010, 2012; see Dreisbach & Fischer, 2012a for a review). The role of affect in sequential conflict adaptation is of specific interest here due to the increasing evidence that conflicts themselves are experienced as aversive signals (Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013, 2015; Schouppe et al., 2012; Schouppe et al., 2015). For example, presenting Stroop conflict stimuli (Stroop, 1935) as primes eased the evaluation of negative target stimuli and increased the frequency of negative judgments for neutral target stimuli (Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013; 2015). Converging evidence in favor of the aversive conflict signal also comes from physiological studies showing increased heart rate (Renaud & Blondin, 1997), larger pupil dilatation (van Steenbergen & Band, 2013; Wendt et al., 2014), and enhanced skin conductance response (Kobayashi, Yoshino, Takahashi, & Nomura, 2007) in response to incongruent Stroop stimuli (but see Schacht, Dimigen, & Sommer, 2010, who, however, did not use Stroop stimuli but measured physiological activity during a go/no-go paradigm). Given that conflicts are detected by the ACC, and further given that the ACC is also activated by monetary loss (Rainville, 2002), social exclusion (Eisenberger, Lieberman, & Williams, 2003), negative feedback (Nieuwenhuis et al., 2004), and pain (Singer et al., 2004), one might therefore speculate that it is not the response conflict per se but the aversive character of the response conflict that triggers the processing adjustments (Botvinick, 2007; Dreisbach & Fischer, 2015a, 2015b). In fact, Dreisbach and Fischer (2011) found that aversive stimuli can lead to sequential adaptation effects even in the absence of response conflicts. In that study, the authors made use of the fact that fluency of processing, i.e., the experienced ease of stimulus processing, is affectively marked, with low fluency being associated with negative and high fluency with positive affect (Reber, Winkielman, & Schwarz, 1998; Winkielman, Schwarz, Fazendeiro, & Reber, 2003)[18]. Dreisbach and Fischer (2011) let participants categorize number words according to magnitude that were either written in an easy (fluent) or hard to read (disfluent) font. In three experiments, the authors found sequential modulations of the fluency effect (performance difference between disfluent and fluent trials) in terms of a smaller fluency effect following disfluent trials. Moreover, van Steenbergen and colleagues repeatedly showed that presenting positive symbols in the inter-trial-intervals of an Eriksen Flanker task (Eriksen & Eriksen, 1974) eliminated conflict adaptation effects (van Steenbergen et al., 2009, 2012; but see Stürmer et al., 2011; Braem et al., 2013b, Notebaert & Braem, 2015). Van Steenbergen and colleagues interpreted this result as indication that the positive symbol counteracted the aversive signal of the response conflict and thus eliminated conflict adaptation.

In sum, the observations that (1) aversive signals without response conflict promote sequential processing adjustments (Dreisbach & Fischer, 2011) and (2) positive signals following response conflict eliminate processing adjustments (van Steenbergen et al., 2009; 2012), might suggest that the aversive characteristic of conflicts itself triggers the processing adjustments[19]. One straightforward way to address the question whether it is the aversive conflict signal that triggers conflict adaptation is to increase the aversiveness of a given conflict stimulus and investigate its effects on conflict adaptation. As already mentioned above, perceptual fluency serves as an affective signal with high perceptual fluency being associated with positive affect and low perceptual fluency being associated with negative affect (Reber et al., 1998; Winkielman, et al., 2003). Therefore, we manipulated the aversive quality of a conflict signal by presenting classical response interference tasks either with high

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[18] It is important to note that it has been shown empirically that not only is perceptual fluency associated with positive affect but also that perceptual disfluency is associated with negative affect. In three experiments, Reber et al. (1998) applied different manipulations of perceptual fluency and examined the consequences on preference judgments. In Experiment 1, participants judged drawings that were preceded by mismatching primes (i.e., perceptually disfluent stimuli) as being less pretty than drawings that were preceded by matching primes. In Experiment 3, participants stated to dislike stimuli more that were presented for shorter periods of time than stimuli that were presented for longer time periods. Finally, and most similar to the manipulation of perceptual fluency used in the present study, in Experiment 2, Reber et al. let participants judge circle stimuli that varied in figure ground contrast. They found that the circles were judged as less pretty and more ugly with decreasing figure ground contrast, i.e., with decreasing perceptual fluency.

[19] There are a couple of studies, however, suggesting that it is not the affective value of conflicts but the rewarding effect of conflict resolution that leads to post-conflict adjustment (Braem et al., 2012; see also Schouppe et al., 2015).

perceptual fluency (fluent) or with low perceptual fluency (disfluent), expecting that disfluent incongruent trials are more aversive than fluent incongruent trials. Consequently, if it is an unspecific aversiveness conveyed by the conflict that triggers conflict adaptation, we should find increased conflict adaptation on disfluent trials as compared to fluent trials, as disfluency is assumed to increase the general aversiveness of conflicts even further.

EXPERIMENT 3A

Method

Participants

Thirty students of the University of Regensburg were tested (23 female; 24 right-handers; mean age: 26.6, SD = 4.1). All participants signed informed consent before the experiment and received 3 Euros or partial course credit after its completion. Data of two participants with RTs that were more than 2 SDs above at least one group cell mean were excluded from the analysis, leaving a final sample of 28 participants.

Material and Procedure

Stimuli consisted of a central color-square horizontally flanked by two color-squares, one on each side. The three horizontally aligned squares subtended a visual angle of 19.9° x 6.6° at a viewing distance of 60 cm. Square colors were red, green, and blue. Congruency was manipulated by color match or mismatch: The color of the central square could either match (congruent stimulus) or mismatch (incongruent stimulus) the color of the two flanking squares which were always of the same color. Fluency was manipulated by figure-ground contrast differences. In fluent stimuli, color saturation was 100%, in disfluent stimuli, color saturation was 50%. Fluency of relevant and irrelevant stimulus dimensions was manipulated to the same extent by stimulus contrast such that no effect on the conflict per se is to be expected (Miles & Proctor, 2009). The stimuli were presented centrally on a white background.

Participants were instructed to quickly and accurately identify the color of the central square by pressing one of three keys on a QWERTZ keyboard ("c" for green, "v" for red, "b" for blue, respectively) with their index, middle and ring finger of their dominant hand (see Larson, Kaufman, & Perlstein, 2009, for a similar procedure).

Each trial started with a plus sign as fixation cross for 250 ms, followed by the imperative stimulus that was presented until a response was given. For correct responses, the next trial started after 1000 ms. For errors, the German word for error (Fehler) appeared and remained on screen for 1000 ms. After an additional 500 ms, the next trial started. The experiment started with a short test to exclude color blindness, followed by a color-to-key-mapping practice block of 12 randomly presented imperative stimuli and a second practice block of 24 imperative stimuli where participants were introduced to the fluency manipulation. After that, one practice block of 120 trials followed consisting of 30 congruent and 30 incongruent fluent and disfluent trials, respectively. This practice block was followed by 3 experimental blocks of 120 trials each. Blocks were separated from one another by self-paced breaks. Repetition of identical target stimuli was not allowed. Because we were interested in how fluency modulates conflict adaptation, we presented fluent and disfluent trials in runs of ten in a given block while for the assessment of conflict adaptation, conflict versus non-conflict trials varied randomly from trial to trial. The experiment lasted about 25 minutes.

Design

A 2 (Congruency_{N}) x 2 (Congruency_{N-1}) x 2 (Fluency) repeated measures design was used.

Data preprocessing

We excluded the first two trials of each fluency block of 10 trials length in order to remove possible transition effects from the previous fluency condition. In order to decrease the influence of low-level feature repetitions and to maximize cognitive control involvement in conflict adaptation (e.g., Egner, 2007), partial priming trials (whenever the color of either the central or flanking stimulus repeated from trial N-1 to trial N (42.3%)) and negative priming trials (whenever the color of the flanking squares in trial N-1 was the color of the central square in trial N (18.5%)) were excluded prior to analysis (see also Bugg, 2008; Larson et al., 2009; Ullsperger, Bylsma, & Botvinick, 2005; Wendt et al., 2014)[20]. For error data analysis, mean error rates for the remaining data (on average 134 trials per participant) were computed for each cell of the 2 (Congruency$_{N}$) x 2 (Congruency$_{N-1}$) x 2 (Fluency) design and entered into a repeated measures analysis of variance (ANOVA). Additionally, for RT data analysis, erroneous as well as post-error trials (together 6.7%) and all RTs that exceeded more than two standard deviations from the individual cell mean (4.9%) were excluded prior to analysis. For the remaining data (on average 121 trials per participant), mean RTs for each cell of the 2 (Congruency$_{N}$) x 2 (Congruency$_{N-1}$) x 2 (Fluency) design were computed and a repeated measures analysis of variance (ANOVA) was conducted.

Results and Discussion

Error data

There was a marginally significant interaction of Congruency$_{N}$ x Congruency$_{N-1}$, $F(1,27) = 3.375$, $p = .077$, $\eta^2 = .111$, reflecting a typical conflict adaptation effect. The congruency effect was less pronounced following incongruent$_{N-1}$ (-1.16%) as compared to following congruent$_{N-1}$ trials (2.42%). Importantly, this conflict adaptation effect was further modulated by Fluency, $F(1,27) = 4.675$, $p < .05$, $\eta^2 = .145$ (see Figure 8). In fluent trials, participants showed a significant conflict adaptation effect, $F(1,27) = 5.783$, $p < .05$, $\eta^2 = .176$, i.e., an inverted congruency effect for trials following incongruent trials (-3.67%) as compared to following congruent trials (2.69%). In disfluent trials, however, the effect of Congruency$_{N}$ was unaffected by Congruency$_{N-1}$, $F < 1$, $p > .706$, $\eta^2 < .006$. No further effects were significant, all Fs < 2.873, all ps > .101, all η^2s < .097.

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[20] Because the post-hoc removal of all stimulus/feature repetitions is standard procedure in studying conflict adaptation, the experiment was from the beginning designed to provide a sufficiently large number of trials per cell. An a priory exclusion of critical stimulus sequences was not considered an option as it induces expectation biases. For a recent discussion of theoretical and practical guidelines in the investigations of conflict adaptation see Duthoo et al. (2014) and Egner (2014).

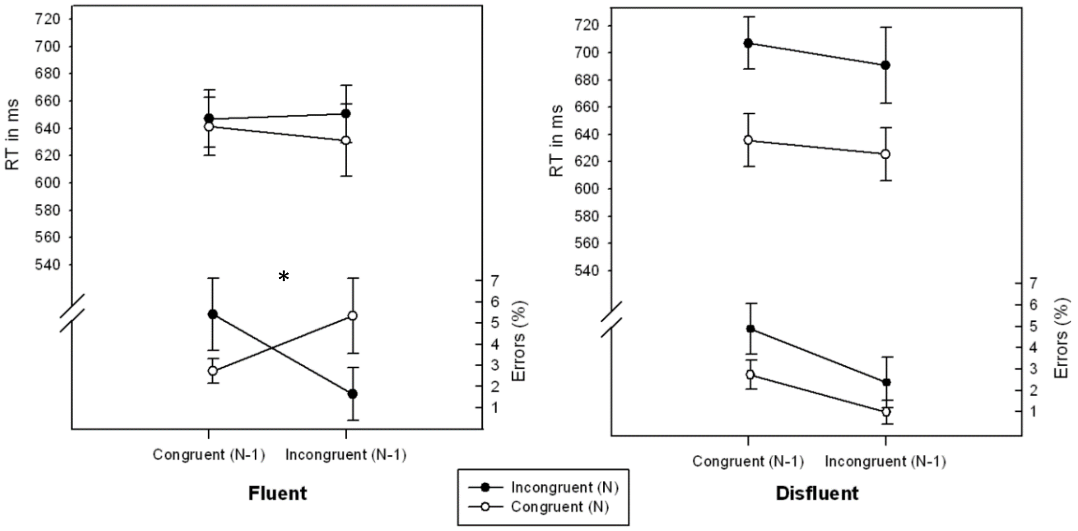

Figure 8. RTs (ms) and error rates (%) as a function of Congruency(N) and Congruency(N-1) for fluent (left panel) and disfluent (right panel) trials of Experiment 3A. Error bars represent standard errors of the mean. *denotes a significant interaction Congruency(N) X Congruency(N-1)

RT data

The main effects of Congruency$_N$, $F(1,27) = 22.515$, $p < .001$, $\eta^2 = .464$, and Fluency, $F(1,27) = 5.051$, $p < .05$, $\eta^2 = .163$, were significant. RT was lower for congruent$_N$ (633.45 ms) as compared to incongruent$_N$ (673.90 ms) trials and lower for fluent (642.59 ms) as compared to disfluent (664.76 ms) trials. Furthermore, there was a significant interaction of Congruency$_N$ x Fluency, $F(1,27) = 7.239$, $p < .05$, $\eta^2 = .218$: The Congruency effect was less pronounced in fluent (12.63 ms) as compared to disfluent trials (68.27 ms). No further effects were significant, all *F*s < 1.019, all *p*s > .321, all η^2s < .039.

The main results of Experiment 3A can be summarized as follows: The higher order interaction of Congruency$_N$ X Congruency$_{N-1}$ X Fluency found in the error data showed the usual significant conflict adaptation effect on fluent trials (i.e., stimuli with high stimulus contrast as used in standard paradigms), and a significantly reduced and virtually absent conflict adaptation effect for disfluent trials. The results thus suggest that, if anything, increasing the general aversiveness of conflicts by reducing the stimulus contrast *eliminates* the conflict adaptation effect. This contradicts the idea that adding unspecific aversiveness to a conflict stimulus increases specific adaptation effects. In order to consolidate the findings from Experiment 3A, we ran a second experiment with a different response conflict paradigm, i.e., a manual version of the Stroop task (Stroop, 1935). If the results from Experiment 3A (the modulation of the conflict adaptation effect by fluency with an elimination thereof in disfluent trials) can be replicated in Experiment 3B, it can be ruled out that the effects were driven by paradigm specific parameters and thus highlight the findings' generalizability.

EXPERIMENT 3B

Method

Participants

Thirty students of the University of Regensburg were tested (23 female; 28 right-handers; mean age: 23.1, SD = 3.7). All participants signed informed consent before the experiment and received 3 Euros or partial course credit after its completion. Data of three participants with RTs that were more than 2 SDs above at least one group cell mean were excluded from the analysis, leaving a final sample of 27 participants.

Material and Procedure

Stimuli were the German color words for RED (rot), GREEN (grün), and BLUE (blau) printed in red, green, and blue (RGB values of 255,0,0; 0,255,0; and 0,0,255, respectively). The words were written in Arial bold, 24 pt, each letter subtending a visual angle of approximately 0.8° x 0.8° at a viewing distance of 60 cm. Congruency was manipulated by color-word match or mismatch: The print color could either match (congruent stimuli) or mismatch (incongruent stimuli) the word meaning of the stimulus. Again, fluency was manipulated by figure-ground contrast differences. In fluent stimuli, color saturation was 100%, in disfluent stimuli, color saturation was 50%. The stimuli were presented centrally on a white background. Participants' task was to quickly and accurately identify the print color of the word while ignoring its meaning by pressing one of three keys on a QWERTZ keyboard ("c" for green, "v" for red, “b” for blue, respectively) with their index, middle, and ring finger of their dominant hand. Trial and block procedure remained the same as in Experiment 3A.

Design

A 2 (Congruency$_{N}$) x 2 (Congruency$_{N-1}$) x 2 (Fluency) repeated measures design was used.

Data preprocessing

We excluded the first two trials of each fluency block of 10 trials length in order to remove possible transition effects from the previous fluency condition. Furthermore, partial priming trials (whenever the color or color word repeated from trial N-1 to trial N (46.6%)) and negative priming trials (whenever the color word in trial N-1 was the color of the stimulus in trial N (16.2%)) were excluded prior to analysis to ensure that priming effects did not mask conflict adaptation. For error data analysis, mean error rates for the remaining data (on average 130 trials per participant) were computed for each cell of the 2 (Congruency$_{N}$) x 2 (Congruency$_{N-1}$) x 2 (Fluency) design and entered into a repeated measures analysis of variance (ANOVA). Additionally, for RT data analysis, erroneous as well as post-error trials (together 7.5%) and all RTs that exceeded more than two standard deviations from the individual cell mean (4.6%) were excluded prior to analysis. For the remaining data (on average 118 trials per participant), mean RTs for each cell of the 2 (Congruency$_{N}$) x 2 (Congruency$_{N-1}$) x 2 (Fluency) design were computed and a repeated measures analysis of variance (ANOVA) was conducted.

Results and Discussion

Error data

There was a significant main effect of Congruency$_{N}$, $F(1,26) = 16.335$, $p < .001$, $\eta^2 = .386$, and a marginally significant effect of Fluency, $F(1,26) = 3.028$, $p = .094$, $\eta^2 = .104$. Error rates were lower for congruent$_{N}$ (2.39%) as compared to incongruent$_{N}$

(4.65%) trials and lower for fluent (3.19%) as compared to disfluent trials (3.85%). No further effects were significant, all *F*s < 2.331, all *p*s > .138, all η^2s < .083.

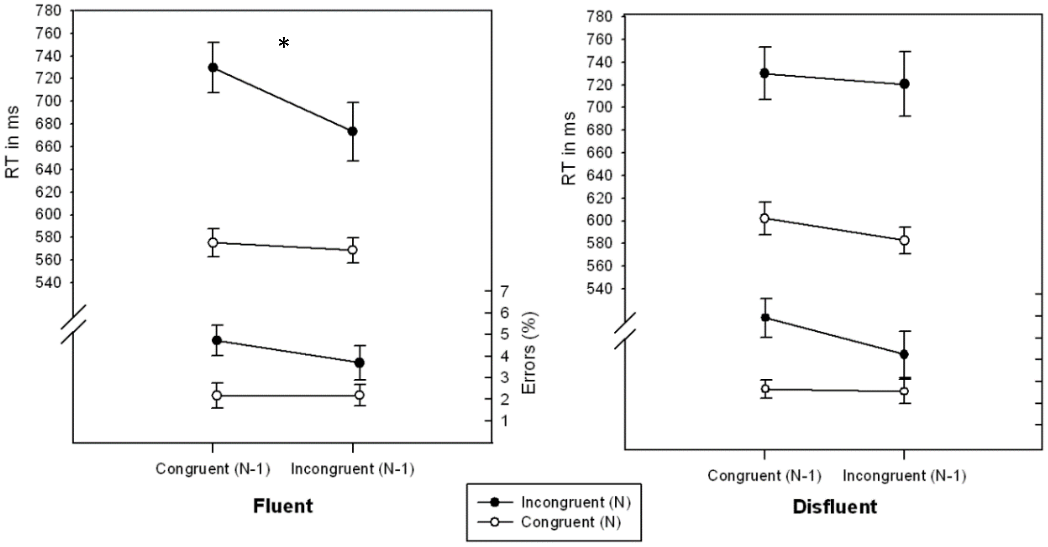

Figure 9. RTs (ms) and error rates (%) as a function of Congruency(N) and Congruency(N-1) for fluent (left panel) and disfluent (right panel) trials of Experiment 3B. Error bars represent standard errors of the mean. *denotes a significant interaction Congruency(N) X Congruency(N-1)

RT data

The main effects of Congruency$_N$, *F*(1,26) = 86.941, *p* < .001, η^2 = .770, Congruency$_{N-1}$, *F*(1,26) = 10.821, *p* < .01, η^2 = .294, and Fluency, *F*(1,26) = 5.371, *p* < .05, η^2 = .171, were significant. RT was lower for trials following incongruent trials (636.34 ms) as compared to congruent trials (659.30 ms), lower for congruent$_N$ (582.21 ms) as compared to incongruent$_N$ (713.42 ms) trials and lower for fluent (636.71 ms) as compared to disfluent (658.92 ms) trials. As in the accuracy data of Experiment 1, the interaction of Congruency$_N$ x Congruency$_{N-1}$ x Fluency was significant, *F*(1,26) = 6.604, *p* < .05, η^2 = .203 (see Figure 9). In fluent trials, participants showed a significant conflict adaptation effect, *F*(1,26) = 8.220, *p* < .01, η^2 = .240, i.e., a smaller congruency effect for trials following incongruent trials (104.56 ms) as compared to following congruent trials (154.42 ms). In disfluent trials, however, the congruency effect was unaffected by Congruency$_{N-1}$ (137.98 ms following incongruent and 127.86

ms following congruent trials), $F = .323$, $p = .574$, $\eta^2 = .012$. No further effects were significant, all Fs < 1.932, ps > .175, all η^2s < .070.

In Experiment 3B, the higher order interaction Congruency$_N$ X Congruency$_{N-1}$ X Fluency was significant in the RT data. Again, the conflict adaptation effect was only significant in fluent trials but was eliminated in disfluent trials. Taken together, both experiments brought up converging evidence that sequential conflict adaptation, if present in fluent trials, is entirely reduced in disfluent trials. This contradicts the idea that any aversive signal is suited to trigger stimulus-specific adaptation effects.

GENERAL DISCUSSION

Based on a theoretical framework of ACC functioning (Botvinick, 2007) and recent findings of (1) conflict aversiveness (Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013; 2015; Schouppe et al., 2012; Schouppe et al., 2015), (2) elimination of conflict adaptation by positive action effects (van Steenbergen et al., 2009; 2012), and (3) sequential adaptation triggered by non-conflict aversive (disfluent) stimuli (Dreisbach & Fischer, 2011), we directly tested whether increasing the aversive value of conflict stimuli also increases sequential adaptation effects. To this end, we presented conflict stimuli with either high or low perceptual fluency. Because disfluency is experienced as aversive signal (Reber et al., 1998), this manipulation is suited to modulate the affective valence of conflict stimuli. If conflict adaptation is triggered by the aversive nature of conflict stimuli independently from the conflict information, then the increased negative valence of disfluent incongruent as compared to fluent incongruent trials might increase adaptation effects.

Results from both experiments, however, did not support this idea. In contrast, whenever the typical conflict adaptation was found for fluent trials (in the error data in Experiment 3A and in the RT data in Experiment 3B), disfluency eliminated conflict adaptation effects entirely. And this cannot be explained by reduced conflict strength on disfluent trials because conflict was either unaffected by the fluency manipulation (Experiment 3B) or even increased (Experiment 3A) for disfluent trials[21]. In both

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[21] Miles and Proctor (2009) found that decreasing both, the discriminability of the relevant and irrelevant stimulus feature, does not change the magnitude of the congruency effect in two response conflict

experiments, conflict adaptation was only present in one of the dependent measures, i.e. error rates in Experiment 3A and RT data in Experiment 3B. Thus, neither RT data in Experiment 3A nor error rates in Experiment 3B were further modulated by disfluency. Indeed, there have been many studies reporting similar findings, i.e., conflict adaptation effects being only present in RT data OR error data (see e.g. Bugg, 2008; Ullsperger et al., 2005; Puccioni & Vallesi, 2012; Soutschek et al., 2012; van Steenbergen et al., 2010; 2012). So far, there has been no study that directly addressed why the conflict adaptation effect is sometimes found in the RT data while it is found in the error data in other cases. The important result of our study, however, is that the dependent measure that showed the typical conflict adaptation effect on fluent trials in the respective experiment (i.e., error rates in Experiment 3A and RT data in Experiment 3B) also brought up a higher order interaction with fluency: While conflict adaptation is intact on fluent trials, disfluency leads to its elimination. These consistent findings from two independent experiments have an important implication: They demonstrate that increasing unspecific aversiveness, for example by decreasing fluency of processing, does not inevitably lead to stronger conflict adaptation but in contrast may even diminish it. Thus, it is conceivable that aversiveness might need to be tied to conflict processing and not to stimulus processing in general.

An important question, however, remains: why does reduced fluency of processing (and thus, increased aversiveness) not only *not* increase or not affect conflict adaptation, but eliminates it? Here, a potential answer could be that reducing fluency of processing might come with side effects other than the aversive connotation that could directly have affected conflict adaptation. For example, processing of disfluent stimuli might have increased processing demands and invested effort (e.g. Dreisbach & Fischer, 2011). There is already ample evidence that conflict adaptation is modulated by processing demands of primary task processing. For example, Fischer, Dreisbach and Goschke (2008) had participants complete a number magnitude task (i.e., indicate whether a given number was bigger or smaller than 5) combined with a

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paradigms. Thus, we assumed that in our experiments, the fluency manipulation would likewise leave the congruency effect unaffected. However, the interaction of fluency with congruency was significant for the Flanker task in Experiment 3A. Although we do not have an explanation for this effect, still, this does not weaken our argument: conflict adaptation is absent in disfluent as compared to fluent trials even though conflict magnitude was bigger in disfluent trials. It seems thus that the demotivating effect of continued disfluency (see Discussion below) overrules the effect of enhanced conflict aversiveness.

Simon task (i.e., numbers appeared on the right or left side of the screen). They found the typical sequential conflict adaptation in the Simon task which was further modulated by the cognitive demand of the number magnitude task: Following numbers close to the reference standard (high processing demand), the Simon adaptation was smaller than following numbers far from the reference standard (low processing demand). Likewise, Soutschek, Strobach, and Schubert (2012) reported evidence that high working memory load eliminates conflict adaptation in the Stroop task. Applied to our results presented here, one might thus argue that disfluent trials draw on processing resources that were then not available for conflict adaptation. Does that imply that the aversive character of disfluency had no effect in our study? Interestingly, Pessoa (2009) claimed that not only different cognitive processes share and compete for the same restricted resource capacities, but that cognitive and affective processes do so as well. Indeed, it has been shown that performance in incongruent trials decreased when preceded by an affective task-irrelevant picture (Hart et al., 2010), suggesting that the processing of the affective stimulus consumed resources that would otherwise have benefited conflict resolution. In the same line and more directly related to our study, Padmala, Bauer, and Pessoa (2011) reported that presenting highly arousing negative pictures as compared to neutral pictures in inter-trial-intervals of a Stroop-like word-face task eliminated conflict adaptation effects (see also Braem et al., 2013b). The authors, too, explained this finding in terms of resource competition: The resources that are necessary for post-conflict adaptation were consumed by the processing of the arousing aversive pictures and were then lacking for conflict adaptation. In the light of these findings, the resource competition account might explain our data, as well. As disfluency is associated with negative affect, the processing of the aversive quality in disfluent blocks may have demanded resources that would otherwise have been used to adapt control in post-conflict trials[22].

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[22] An alternative, yet similar, explanation of reduced conflict adaptation effects in affectively negative conditions grounds on the idea that the effects of negative mood (cf. van Steenbergen, 2015) or more generally, arousal (cf. Braem, Duthoo and Notebaert, 2013a), on cognitive control follow an inverted U shaped function: while moderate levels of arousal are beneficial for cognitive control processes, too little or too much arousal is detrimental. For example, Braem et al. (2013b) found that the influence of punishment on conflict adaptation critically depends on individual punishment sensitivity: while punishing individuals low in punishment sensitivity (as measured with the Behavioral Inhibition System (BIS) scale) increased conflict adaptation in post-punishment trials, punishing highly punishment sensitive participants did not modulate conflict adaptation but lead to a general slow-down in RTs in post-punishment trials. The authors interpret their data in the framework of the Yerkes-Dodson law (Yerkes & Dodson, 1908) and suggest that for highly punishment sensitive individuals, punishment-associated

A second, very recent line of research that is of interest to our results deals with the motivational impact of conflict resolution on conflict adaptation. According to this adaptation-by-motivation account, conflict adaptation is triggered by the rewarding experience of conflict resolution (Braem et al., 2012). This idea is grounded on the observation that solving a difficult task is more rewarding than solving an easy task (Shalley & Oldham, 1985; Satterthwaite et al., 2012). For example, Satterthwaite and colleagues used an n-back task and could show that the activation in the ventral striatum, a key region of dopamine production, increased with increasing task difficulty. The most direct evidence for the role of reward for conflict adaptation has recently been put forward by Braem and colleagues (2012). In that study, participants were presented with an Eriksen Flanker task (Experiment 1). In the experimental condition, 25% of trials of a given block were rewarded for correct and fast performance, whereas in the remaining 75% of the trials, no reward was given. In the control condition, no reward was given ever. Results brought up sequential conflict adaptation effects in the control condition (no reward) and in rewarded trials in the experimental condition. Intriguingly, no such conflict adaptation was found for unrewarded trials in the reward context. According to the authors, the extrinsic reward signal on 25% of trials replaced or overshadowed the intrinsic reward signal normally generated in standard (no-reward) conflict tasks. As a consequence, the no-reward trials lacked the intrinsic rewarding experience that would have been necessary to trigger conflict adaptation.

Back to the data presented here, the adaptation-by-motivation account also fits with our findings. Notably, fluency of processing has been shown to modulate motivation directly. For example, Song and Schwarz (2008) found that participants were less motivated to carry out a task that was described in a hard to read (disfluent) font as compared to a task described in an easy to read (fluent) font. Applied to our experiments, the continuous experience of disfluency throughout the mini-blocks of disfluent trials might have reduced the motivation to adapt. Put differently, in disfluent mini-blocks, the rewarding effect of a successful conflict resolution might have been counteracted by the discouraging continuous disfluent experience. Therefore, the

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arousal was too high to benefit conflict adaptation. However, we do not think that this framework is suited to thoroughly explain our results, given that disfluency can hardly be compared to the aversive experience of punishment.

repeated disfluent experience eliminated the intrinsic reward signal that typically follows successful conflict resolution, thereby decreasing the conflict adaptation effect. Further support for this motivational account comes from studies showing that an increase in participants' motivation goes along with decreased RTs and error rates and decreased congruency effects, mimicking our results in the fluent as compared to the disfluent conditions (e.g., Padmala & Pessoa, 2011; Soutschek, Strobach, & Schubert, 2014; Veling & Aarts, 2010).

In sum, the two accounts presented above, i.e., the adaptation-by-motivation account, and the resource competition account, are equally well suited to explain our results. In fact, they are not mutually exclusive but closely intervened. After all, the negative valence of disfluency (just as the negative valence of conflict stimuli, see Botvinick, 2007) might at least in part be due to the increased processing demands of disfluent (and incongruent) trials. The only caveat might be that our results are hard to reconcile with the interpretation of van Steenbergen and colleagues (2009) outlined in the Introduction. To reiterate, the authors found no conflict adaptation following positive signals and argued that the positive signals presumably counteracted the aversive character of the conflict stimulus. Alternatively, and in line with the adaptation-by-motivation account, the positive signals in the van Steenbergen study that were presented as non-contingent performance feedback might have signaled that successful performance is not a value by itself and thereby counteracted the intrinsic reward signal (see also Dreisbach & Fischer, 2012a, for a more thorough discussion). In sum, random reward (van Steenbergen et al., 2009, 2012; see also Stürmer et al., 2012), no-reward in a reward context (Braem et al., 2012) and repeated experience of disfluency (the results presented here) have all been found to reduce or eliminate conflict adaptation. The common underlying mechanism might be that in all these situations, the intrinsic reward signal after successful conflict resolution was reduced.

It is important to note that the present findings and the suggested interpretations do not at all contradict the repeatedly shown aversive nature of conflict stimuli and their role for conflict adaptation (Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013, 2015; Schouppe et al., 2012; Schouppe et al., 2015). What we have shown here is that increasing the negative valence of conflict stimuli via disfluency (and thus independently from conflict strength) does not increase conflict adaptation effects. But at the same time, it is well documented that (1) disfluency triggers processing adjustments in terms of a reduced fluency effect (Dreisbach & Fischer, 2011) and that (2) conflict adaptation effects increase with increasing conflict strength (Forster et al., 2011; Takezawa & Miyatani, 2005; Wendt et al., 2014). Therefore, we argue that the aversive signal conveyed by the amount of conflict triggers conflict adaptation. Yet it seems that aversive stimulus information from different sources (here: from perceptual fluency vs. response conflict) does not add up to increase sequential conflict adaptation. That is, the aversiveness must be tied to conflict processing and not to stimulus processing in general.

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PART III

CONCLUDING DISCUSSION

SUMMARY OF FINDINGS

In this thesis, three studies are presented that aimed at elucidating the characteristics and function of the affective value of conflicts in information processing.

STUDY 1 reinvestigated the conflict priming effect as found by Dreisbach and Fischer (2012a), using a different dependent variable to yield more unequivocal results. In two experiments, participants had to judge the valence of affectively neutral German words (Experiment 1A) or Chinese pictographs (Experiment 1B) after being primed by conflict or non-conflict Stroop primes. The results show that conflicts indeed are experienced as aversive events and that this affective connotation spills over to subsequently presented stimuli, influencing the way they are processed: being primed with conflicts, participants more often judged the following words or pictographs as negative compared to being primed with non-conflict stimuli.

STUDY 2 aimed at exploring the time characteristics of conflict aversiveness. It was expected that Stroop conflict/non-conflict primes share the same time characteristics as other affective primes, evoking strong priming effects already with short SOAs. Indeed, this is what was found in two experiments: Participants again had to judge the valence of neutral German words after being primed by conflict or non-conflict Stroop primes. SOAs between prime and target presentation varied between subjects, rendering conditions with SOAs of 200 ms, 400 ms and 800 ms. Experiments 2A and 2B showed that conflict priming was already present with SOAs as short as 200 ms, highlighting the automaticity of the processing of conflict-induced affect. Furthermore, Study 2 revealed that with increasing prime presentation duration, the conflict priming effect is actively counter-regulated: Comparing SOA 800 ms conditions over all three experiments shows that with short prime presentation (200 ms, Experiment 2B), typical conflict priming is observed; with longer prime presentation (400 ms, Experiment 2C), conflict priming descriptively reverses and with maximum prime presentation (800 ms), conflict priming is significantly reversed: here, neutral German words are judged more often as *positive* after conflicts as compared to after non-conflict primes.

STUDY 3 was designed to test the hypothesis that conflict aversiveness is the motivator of conflict adaptation. To this end, in two standard reaction time tasks (a color version of the Eriksen Flanker task, Experiment 3A; a manual version of the Stroop task, Experiment 3B), stimuli’s aversiveness was manipulated by varying figure-ground-contrast. Disfluency (reduced figure-ground-contrast) is a known source of negative affect. Thus, it was expected that if it is the conflict stimulus’ aversiveness that promotes conflict adaptation, disfluent trials should result in increased conflict adaptation effects. However, Experiments 3A and 3B yielded opposite effects: disfluency resulted in an elimination of conflict adaptation effects. It was concluded that in order to motivate adaptation, the aversiveness might have to be tied explicitly to the conflict itself rather than to the conflict stimulus in general.

THE MYTH OF THE EMOTIONAL VERSUS THE COGNITVE BRAIN

As elaborated in the first part of this thesis, over the past decades there has been a great deal of research on the exact function of the ACC. However, one of the most basic prevailing questions up to date is whether emotional processes and processes of cognitive control are represented in the same anatomical subdivisions of the ACC. Dealing with this question, reviews have been published that collected, meta-analyzed and (re-)interpreted huge amounts of (neuro-)anatomical, electro-physiological, and functional imaging studies. While the earlier reviews (for example, Bush et al., 2002; Devinsky, Morrell, & Vogt, 1995) supported a segregated view of ACC functioning, in a more recent review, Shackman and colleagues (2011) conclude on the basis of new data that gathered along the years that this segregationist model of ACC functioning is no longer tenable.

In that review, Shackman and colleagues report an abundance of studies showing that the very same regions of the ACC that are engaged in cognitive control processes are also engaged in conditions of autonomic regulation, the perception and production of emotion, as well as in the experience of pain and in the experience of other aversive stimuli. They also give an overview of the profound structural connections between the ACC and other regions highly involved in emotional processing, such as the ventral tegmental area (VTA) and facial muscles linked to the execution of emotional expressions. Finally, the authors review evidence indicating functional convergence of allegedly ‘hot’ and ‘cold’ cognitive processes by showing that measures of negative affect and cognitive control covary.

Thus, in a nutshell, Shackman and colleagues conclude that the data as available in 2011 strongly suggest that the ACC hosts a domain-general process that is fundamental to both cognitive control and emotional processes. In their view, the activation of the ACC in cognitive control tasks as found in the laboratories today actually goes way back to the ACC's evolutionarily older role of regulating emotional processes. That is, Shackman and colleagues put forward that there actually is no such thing as a strictly 'cold' cognitive process (and consequently that there is no brain region that deals with 'cold' cognitive processes per se), but that these are more abstract instances of 'hot' emotional processes that have developed as a byproduct of our cognitive evolution.

In the same line, Inzlicht, Bartholow, and Hirsh (2015) suggest that negative affect is a basic aspect of cognitive control, inasmuch as that cognitive control may also be understood as an emotional process itself. They argue that when decomposing both emotional and cognitive control processes to their more primitive constituting elements, their resemblance unfolds. According to Inzlicht and colleagues, both episodes of emotional experience (in the classical sense) and episodes of cognitive conflict experience can be broken down into three well-defined steps: (1) A preceding event that (2) instigates a cascade of different 'emotional' primitives such as changes in facial expression, affect, physiological responses, subjective experience, attribution, and so forth, which eventually (3) motivates the execution of controlled, goal-directed behavior. Thus, similar to Shackman and colleagues, Inzlicht and colleagues suggest that there is no such thing as an 'emotional brain' that processes affective events and a 'cognitive brain' that processes non-affective events. In their view, cognitive control is an instance of emotional processing itself.

The findings presented in this thesis perfectly fit with this non-segregated view of emotional and cognitive processes and fill some small, but important gaps in research. Studies 1 and 2 offer evidence that conflicts in information processing, which have long been seen as 'cold' cognitive phenomena, can actually be interpreted as 'hot' emotional events that prompt a row of emotional primitives. By 2011, evidence in favor of this hypothesis has only been available on a physiological level. That is, while there have been studies showing that conflicts activate the same brain region that is activated by pain and other aversive stimuli (i.e., the ACC; Shackman et al., 2011) and that furthermore, the experience of conflicts induces an increase in sympathetic nervous activity (Hart et al., 2010; Kobayashi et al., 2007), there had been no study showing any direct evidence that conflicts are actually experienced as aversive *on a behavioral level*.

The first study that offered direct evidence that conflicts affect subsequent behavior in the same way as more typically considered-so emotional events do was the study by Dreisbach and Fischer (2012a), showing that priming with conflict stimuli eases the categorization of negative affective word and picture stimuli, most likely by pre-activating a negative semantic network. Because the conflict priming effect as found in that study was however not unequivocal due to the possibility of a confound with processing fluency (see the introduction of Study 1 for a more detailed description), the results of Study 1 of this thesis (and its replication in Study 2) offered (1) more clear-cut evidence for the aversiveness of conflicts and (2) evidence that conflicts induce yet another emotional primitive that is also typically induced by other affective stimuli: the negative evaluation of subsequently presented material. Thus, the results of studies 1 and 2 further strengthen the comparability between conflicts and other emotional events[23].

Furthermore, also the findings of this thesis' Study 3 fit with the view that there exists a domain-general function which is represented in the ACC and which is integral to both 'cognitive' as well as 'emotional' processes. To recapture, in Study 3, it was shown that adding unspecific aversiveness on a (mini) block level counteracts conflict adaptation. This fits with an idea already claimed by Pessoa in 2009, stating that affective and cognitive processes share the same resources, which in effect is detrimental under some circumstances. For example, Padmala et al. (2011) found that presenting negative pictures in the inter-trial-intervals of a conflict task eliminated conflict adaptation. Likewise, it was shown in Study 3 of this thesis that adding unspecific aversiveness to small blocks of trials in a conflict task eliminated conflict adaptation in these blocks. It seems that in these studies, the processing of negative affect used up cognitive resources by occupying domain-general functions that would

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[23] Schouppe and colleagues (2012) have shown more recently that cognitive conflicts induce avoidance behavior in subjects. This adds to the literature presented above and the findings presented in this thesis, showing that conflicts cause the same emotional reactions as more typical emotional stimuli do.

otherwise have been available for an adaptation to the experience of conflicts. Thus, the results of the three studies presented in this thesis advocate the disestablishment of a segregationist model of ACC functioning. It would be interesting to examine the underlying functional connections of the emotional processes induced by conflict stimuli in more detail in future studies.

FIGUREING OUT THE FUNCTION OF CONFLICT AVERSIVENESS

To come back to the starting point of this thesis, results of Study 1 (and their replication in Study 2) help filling another important gap in research by supporting the underlying conclusion made in the extended CMT by Botvinick in 2007. Here, the idea that *any* aversive signal is suited to induce control adaptations implies that conflict stimuli, which are known to instigate such control adaptations, do necessarily have to be aversive, too. Studies 1 and 2 of this thesis as well as several other recent studies in the field (Dreisbach & Fischer, 2012a; Schouppe et al., 2012; van Steenbergen, Band, & Hommel, 2009; 2012) support this conclusion: conflicts are aversive signals. Now, not only is this finding bridging the gap between allegedly ‘hot’ and ‘cold’ sights of the brain, it is also helpful when trying to understand the mechanism behind conflict adaptation.

The extended CMT, when looked at in a broader context, can be interpreted as the neuronal elaboration of a much older concept in psychology: operant conditioning, or, more precisely, punishment (Skinner, 1938). According to both the extended version of the CMT and operant conditioning theory, aversive events in the processing stream lead to adaptations in behavior that make the re-occurrence of these aversive events less likely. In the extended version of the CMT, this account is anatomically explicated by giving the ACC the role of the ‘aversiveness detector’ and the (dl)PFC the role of the executor of behavioral changes. Now, when trying to answer the question regarding the *function* of conflict’s aversiveness, the parallel to Skinner’s reinforcement learning account may be helpful. The function of the negative affect as induced by conflicts may be that it *motivates* subsequent behavioral changes, making it a necessary precondition for the respective behavioral changes to occur.

This idea was examined in Study 3 of this thesis. To recapture, negative affect was added to small blocks of conflict and non-conflict stimuli by decreasing figure-ground contrast (i.e., by adding disfluency, a known inducer of negative affect). The results showed that adding unspecific negative affect to a conflict task does not, as anticipated, increase, but eliminate conflict adaptation. This result was unexpected at first sight, but when looked at closer, fits very well with the idea that the aversiveness that actually motivates task-benefitting strategy changes has to be tied to the specific task *itself*. For example, in the study by Dreisbach and Fischer (2011), the task was to categorize number words as fast as possible, and thus the negative affective experience of a disfluent, hard-to-read trial resulted in a subsequent change in the perceptual processing of exactly these number words. While in Study 3 of the present thesis, perceptual disfluency of conflict trials may also have changed subsequent perceptual/semantic processing in general, it did not cause enhanced shielding from interference. Thus, it seems reasonable to assume that only *conflict-induced* negative affect triggers processes of *conflict adaptation*. Intuitively, this seems also to be the most appropriate strategy for adaptive organisms: to prepare *specifically* for the event that most recently caused distress[24].

While the results of Study 3 offer support for the idea that the behavioral changes that manifest after experiencing negative affect are tied specifically to an improvement in dealing with the negative affect's source, the question of the exact role of conflict aversiveness in conflict adaptation is still open to debate. The best way to directly test the hypothesis that conflict adaptation depends on conflict aversiveness would be to manipulate the aversiveness induced by a conflict stimulus without changing the conflict magnitude itself. Actually, there have been studies reporting decreased ERN amplitudes and post-error adjustment after alcohol consumption (Ridderinkhof et al., 2002) or anxiolytic drug intake (de Bruijn, Hulstijn, Verkes, Ruigt, & Sabbe, 2004; McNaughton, Swart, Neo, Bates, & Glue, 2013). Critically, these effects are supposed to be mediated by a drug-induced decrease in the negative affect caused by errors (Bartholow, Henry, Lust, Saults, & Wood, 2012; see also Inzlicht et al., 2015). However, though the results of these studies are very promising, the fact that the effects of psychopharmacological medication on information

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[24] This fits with studies showing cross-task adaptations only under circumstances of high stimulus similarity (Kunde & Wühr, 2006; Notebaert & Verguts, 2006). However, it seems reasonable that there still are other, more general adaptations in reaction to negative affect that operate in parallel to more specific processes. An example for such more general adaptation effects might be the more cautious behavior after errors, the so-called post-error slowing (Botvinick et al., 2001).

processing are manifold and still largely unknown advocates for a cautious interpretation thereof.

Another plausible way to test the functional relevance of conflict aversiveness in conflict adaptation would be to investigate the co-variation of inter-individual differences in conflict priming and conflict adaptation effects. More specifically, it would be interesting to see if participants who show strong conflict priming effects (i.e., experience strong negative affect induced by conflicts) also show increased conflict adaptation effects (i.e., are more motivated to adapt because of the more negative conflict experience). When designing such an experiment, it would be crucial to also control for mediator variables that may alienate real effects. For example, it might be that some individuals indeed experience conflicts in information processing as negative, but lack the cognitive resources needed to resolve them properly. For example, there have been studies showing that individuals with high trait anxiety respond to errors with enhanced ACC activation (Cavanagh & Shackman, 2014; Moser, Moran, Schroder, Donnellan, & Yeung, 2013), but fail to use these aversive signals adaptively (Bishop, 2008; Eysenck & Derakshan, 2011). Recent theories assume that the extreme sensitivity of highly anxious people to potential threat results in a constant distraction from active goal maintenance by (potentially dangerous) environmental stimuli. Thus, first, trait anxious individuals have less resources available to support cognitive control processes (Pessoa, 2009) and, second, the negative affect of conflict stimuli, against a background of many other stimuli that are subjectively experienced as aversive, may not be as prompting as in healthy or ‘normally’ anxious people (see Inzlicht et al., 2015, Box 2, for a distinguished summary of current literature on that topic).

Transferred to the design of Study 3 of the present thesis, the interpretation of anxious individual’s incapacity to make use of conflict aversiveness in an adaptive way bears an interesting idea for future usage of this paradigm. Disfluent blocks could be interpreted as experimental inductions of highly trait anxious people’s natural environment, making it impossible to adapt to conflicts when there is a lot of added potential threat, i.e., negative affect induced by disfluency. Thus, the paradigm of Study 3 could be used as a more direct measure of trait anxiety (compared to questionnaires), in such a way that people with higher levels of trait anxiety should show worse conflict adaptation than people with lower levels of trait anxiety, especially so in disfluent blocks. In the same line, it might also be used as a treatment check: symptom improvement in the cause of psychological or medical therapy should go along with improvements in conflict adaptation effects for trait anxious people, especially so in disfluent blocks.

To sum up, while more direct evidence for a causal role of conflict aversiveness in conflict adaptation is still missing, results that favor this idea are proliferating. Next to studies already mentioned above (Bartholow et al., 2012; van Steenbergen et al., 2009; 2012), other work that has to be mentioned in this context is a very recent study by Desender, van Opstal, and van den Bussche (2014). Here, subjects participated in a masked conflict priming paradigm and were asked after each trial if they had experienced a conflict or not. Results of that study showed that conflict adaptation was only present when participants stated to have actually experienced the previous conflict. That is, the authors conclude, what drives conflict adaptation is not conflict per se, but it’s subjective experience. In future studies, it would be interesting to more precisely analyze what subjective experience it actually is that lets participants reach the conclusion to have experienced a conflict – it might be that it is the experience of aversiveness, after all.

CONCLUSION

The findings presented in this thesis add to an increasing field of research that supports the establishment of a non-segregated view of emotional and cognitive processes: conflicts, formerly believed to be ‘cold’ cognitive processes, are experienced as aversive and induce emotional primitives such as negative evaluation (Studies 1 and 2). Moreover, the results presented in this thesis highlight the importance of negative affect in behavioral control. Based on the studies presented here (particularly Study 3) as well as work recently published by other labs, it seems that the function of conflict-induced aversiveness is to *motivate* the system to engage in behavior that counteracts the experience of negative affect. Depending on the situation at hand, the counteraction of negative affect is realized by either the elimination of its cause (if, for example, conflict solution is possible) or by more direct affective counter-regulation strategies (if, for example, conflict solution is impossible, see Study 2). Thus, together with other recent research, the results of this thesis suggest that conflict aversiveness is mandatory for conflict adaptation (and for affect regulation in general). This assumption offers fruitful soil for future research and will certainly be tested more specifically in future studies.

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